Measurement of the Age of Plutonium - Beryllium Source Neutrons in Water

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DEDICATED TO

DEAR [illegible] FATHER

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CERTIFICATE

This is to certify that present work has been carried out under my supervision and the work has not been submitted else-where for a degree.

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LIST OF SYMBOLS

τ - Neutron age

E - neutron energy

q (r, E) - Slowing down density of neutrons past the energy E at a distance r from the source

ϕ(r, E) - flux density at a distance r from the source

N - atom density (atoms / cm^3)

σ - microscopic cross section

Σ - macroscopic cross section

ξ - Average logarthmic energy decrement per collision

t - time

S (E) - source spectrum

B - Background counts

C - counts with a foil

L - Diffusion length

ρ - Density

V - Volume of the foil

A (r) - Saturated activity of the foil at a distance r from the source.

A (r) r^2 - The 2nd moment of activity w.r.t distance r

A (r) r^4 - The 4th moment of activity w.r.t distance r

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ABSTRACT

The aim of the present investigation has been to make a new and more accurate measurement of the age of Plutonium Beryllium source neutrons in water. This has been the first among the series of age determination experiments that will be done in the Nuclear Engineering Laboratory.

A literature survey on the age measurements has been made with a brief reference to the historical disagreement between theoretical and experimental values of the age of fission neutrons to Indium resonance. The age of neutrons of the Plutonium-Beryllium neutron source to Indium resonance has been experimentally measured using the foil activation method. The corrections to be made on the measured value of the age due to finite size of the source, change in the density of water etc. are calculated.

The flux perturbation due to introduction of a different material in a medium is negligible if the moderating ratio of that material is the same as that of the medium. Hence the flux perturbation caused by the structural elements used in to hold and suspend the source, foils etc. has been minimised by making them out of materials like Perspex (Lucite) and nylon which have similar slowing down properties as that of water. The activity of the Indium foil is corrected for the contribution of the activity due to high energy neutrons. An error analysis of the experiment is done and the error in the final age value due to error in the distance measurements has been calculated.

CHAPTER I

I INTRODUCTION

1.1 Purpose of the work

The age of a neutron in a medium is a measure of the slowing down length between two energies say from fission energy to thermal energy. Actually, the age of a neutron in a moderating medium is defined as one sixth the average square distance a neutron travels during slowing down from a high energy to a lower energy. Thus the importance of age measurements lies in the fact that the age value of neutron gives an idea of the leakage in a finite nuclear reactor system. Thus, the age value is one of the important reactor design parameters.

A series of age determination experiments with different moderating media such as pure water, Aluminum water mixtures etc. are proposed to be performed in the Nuclear Engineering Laboratory. The present experiment is the first one in this series. It includes setting up of the hardware apparatus and the counting system and then the measurement of the age of Pu - Be neutrons in pure light water. The results of this measurement add to the experimental evidence for the historical disagreement between theoretical and experimental values of the age of neutrons in hydrogeneous media.

1.2 Review of the literature on age

There is considerable amount of interest in the age determination experiments because of the disagreement between the theoretical and experimental values of age of neutrons in hydrogeneous moderating media. This disagreement has been well established for the case of the age of fission energy neutrons to Indium resonance. Doerner et. al.[2] have given a good review of computed and measured ages of fission energy neutrons to Indium resonance. In tables 1 and 2 some of their data are reproduced to show this discrepancy. The calculated values of age cluster around 26.0 ± 0.5 cm^2 and the experiments consistently yield values of about 30.5 ± 1.5 cm^2. Thus the experimental values are 20% higher than the theoretical values. Also, a very good review of the reasons for this discrepancy can be found in a paper by Goldstein.[3] The discrepancy is attributed mainly to the errors in the calculated values due to the uncertainties in the oxygen cross section specially at high energies and the uncertainties in the source spectrum.

In the past few years, age measurements in different media with different sources have been carried out. A few of these are mentioned in table 3.

Lombard and Blanchard[6] determined the age of fission neutrons to Indium resonance. This was done to investigate the errors in the experimental value and in an attempt to clarify the outstanding discrepancy between theoretical and experimental

TABLE I

THEORETICAL AGE VALUES OF FISSION NEUTRONS TO 1.46 ev.

Reference	Method	Date	Value of Age to 1.46 ev	Remarks
1	Fourier Transform	1954	25.3	a
2	P_1 and B_1 approximation	1955	25.3	a,b
			23.6	c
			26.8	d
	Selengut Goertzel	1955	30.9	a, e
			28.8	c, e
			32.8	d, e
1	Modified S-G	1955	30.7	
1	Moments Method	1955	25.7	a
	P_1 and B_1 approximation		24.8	a
2	Moments Method	1955	25.8	a
1	Monte Carlo Method	1956	25.6 $\pm$ 0.3	a, f
2	Moments Method	1957	26.0	a, g
2	Fourier Transform	1957	25.9	a, g
2	Monte Carlo Method	1957	26.7	a, f
2	Moments Method	1957	26.5	a, g
2	Monte Carlo Method	1958	25.9	a, f, g

a : Oxygen slowing down treated exactly.

b : either P_1 or B_1 approximation gives correct 2nd moment for H_2.

c : Oxygen slowing down assumed isotropic.

d : Oxygen slowing down neglected.

e : S-G method known to over estimate the age.

f : Slowing down age corrected to flux age.

g : Revised Oxygen cross sections used.

Ref. 1 : J.E. Wilkins et. al. Proc. Ist. Int. Conf. on peaceful uses of Atomic energy, 5 : 62 (1956)

Ref. 2 : H. Goldstein et. al. Proc. of 2nd. Int. Conf. on peaceful uses of Atomic energy 16 : 379 (1958).

TABLE 2

POINT SOURCE DETERMINATION OF AGE OF FISSION NEUTRONS TO INDIUM RESONANCE

EXPERIMENTER	DATE	AGE VALUE cm^2
Anderson, Fermi & Nagle	1944	32.3
Hill, Roberts & Fitch	1948	30.8
Hoover Arnette	1950	30.03
Wade	1956	31.0
Barkov, Mukhin	1956	29.4 ± 1.6
Blosser Trubey	1959	26.7
Lombard, Blanchard	1960	27.3 ± 0.9
Pettus	1960	27.0 ± 0.9

TABLE 3

Date	Investigators	Medium or Media	Source	Age Values cm^2
1960	Graham Foster Jr[4]	Water and Kerosene	Na-Be(mono energetic source)	13.9 ± 0.2 (water) 13.8 ± 0.2 (Kerosene)
1960	W.G. Pettus[5]	Water	U^{233} fission source	27.6 ± 0.6
1961	Doerner et. al[2]	Water	Fission neutrons	27.68 ± 0.1
1961	Spiegel & Richardson[7]	Heavy Water	$D(d,n)He^3$	119.1 ± 1.5
1961	Cooper[8]	D_2O and H_2O	$D(d,n)He^3$	36.7 ± 2.1 (H_2O) 121.1 ± 1.5 (D_2O)
1961	H.Goldstein & Certaine[9]	D_2O, D_2O-H_2O & metal mixtures	Fission neutrons	118.6 ± 1.2 (D_2O)
1961	De Juren et. al[10]	Water	$D(d,n)He^3$	54.5 ± 1.4
1964	MAJ Rathur & P J Grant[11]	Water and Graphite	PO-Be	57.4(H_2O), 345.3 ± 5.1(Graphite)
1964	Paschall[12]	Water	Fission neutrons	
1964	Campbell et. al[13]	Graphite	Fission neutrons	307.8 ± 1.9
1964	Grimeland and[14] S Donvold	Concrete	$D(d,n)He^3$	444.0 ± 11.0
1967	J.D. Spencer & T.G. Williamson[28]	Aluminum Water lattices	Fission source	39.96 ± 0.5(Metal/Water)=0.5)
1968	Philip F.Palmedo[15]	Aluminum Water lattices	Fission neutrons	Metal/Water Ratio: 1:1 / 2:1 Parallel 65.4 ± 0.8 / 100.3 ± 1.5 Perpendicular 60.8 ± 0.8 / 92.5 ± 1.3

*All age values are to the Indium resonance energy.

values. The effect of distortion of the flux by the foil was discussed. The activity obtained by measuring only the side of the foil which faced the source is called the front activity and the activity obtained by measuring only the side of the foil which did not face the source is called the back activity of the foil. The expressions for the front and the back activities of the foil, in terms of flux were derived.

Doerner et. al.[2] determined the effect of foil thickness on the ratio of front to back activities of foils. De Juren et. al[10] measured the age of (D,D) source to Indium resonance. They found that the comparison of this age with theory becomes difficult due to the uncertainties in the oxygen cross section at high energies. It was also found that the effect caused by Lucite (Perspex) foil holders in water results in a foil activity change of less than 1%. The correction for the activity of the foil due to the finite extention of foil was analyzed by considering the variation of the foil activity over its surface. This was found to be less than 1%.

Campbell et. al[13] checked the irradiated Indium foils for activities other than the 54.0 minute activity of Indium-116. The only other significant activity was the 4.5 hour activity. But this resulted from the high energy neutrons and only those foils within 4 cms of the fission source were affected.

Rathur and Grant[11] used a novel method for age determination. They used a neutron sensitive scintillation detector covered with cadmium sheet. The number of counts produced by the detector at a particular distance from the source is noted. Then the detector is covered by an Indium foil and the number of counts is noted. The difference in these two counts is taken proportional to the slowing down density past the Indium resonance energy. This method appears to be sensitive, faster and precise for the determination of the slowing down density.

Graham Foster Jr[4] has determined the age of Na-Be neutrons (a monoenergitic source) in pure water and kerosene. The reasons for discrepancy due to uncertainties in the neutron spectrum and due to variation of the cross section of oxygen, do not affect these measurements. Kerosene being a hydrocarbon the second uncertainty is eliminated. The Na-Be source is well known monoenergitic source (970 Kev) and hence the first uncertainty mentioned above is removed. The above two facts were thus confirmed as the age values of Na-Be neutrons in water and kerosene agreed very well with the theoretical values.

1.3 Difficulties and errors in the experimental work:

The difficulties encountered with the experiments are due to errors caused by the finite foil size, finite source size, finite sizes of foil holder and source holder though approximate corrections have been made. But the size of the sources cannot be reduced very much due to the fact that an intense source is

needed to get high activities in the foils for age measurement. The other errors can be minimised by using a minimum of structural material and also using materials having similar slowing down properties as the medium. Since the errors associated with experiment are not completely resolved, considerable uncertainties prevail in these values.

The only measurement made for the age of Pu-Be neutron source in pure water, up to date, is that by Valente and Sullivan.[1] Their experimental value of age of Pu-Be source to Indium resonance is 52.8 ± 2.5 cm^2. They used stainless steel wire to suspend the source and aluminum rods to suspend the foils. The effects of these in water in causing flux perturbation were neglected. Also, they neglected the effect of high energy neutron activation of the Indium foil in age determination. The age of Pu-Be source to silver and Rhodium resonances and the age of Po-Be neutron source to Indium resonance were also determined.

The present work was taken up to make a new and accurate measurement with the Pu-Be source since, not much of experimental data exist and to try and eliminate some of the discrepancies by careful experimentation, like, the errors due to high energy activation of Indium - 115, using nylon thread for suspending foils and source.

CHAPTER II

AGE MEASUREMENT TECHNIQUES

2.1 Expressions for Age

Age of neutrons of energy E_0 to a lower energy E, in a moderating medium is defined as one sixth the average square distance a neutron travels as it slows down from E_0 to E. In an infinite moderating medium, the average square distance is given by

$$\overline{r^2} = \int_0^\infty r^4 \, q\,(r, E)\,dr \Big/ \int_0^\infty r^2 \, q\,(r, E)\,dr \qquad (1)$$

where q (r, E) = slowing down density of neutrons past the energy E at a distance r from the source.

Hence, for a point isotropic and monoenergitic source in an infinite moderating medium the expression for age is given by

$$\tau(E_s \rightarrow E_f) = 1/6 \int_0^\infty r^4 \, q\,(r, E_f)\,dr \Big/ \int_0^\infty r^2 \, q\,(r, E_f)\,dr \qquad (2)$$

where E_s is the source energy and E_f is the final energy to which age is measured.

In practice, most of the sources are polyenergitic and hence age determined from such energy distributed sources, loses its exact definition. Age for such sources is explained in the following manner. For a polyenergitic point source emitting S (E) dE neutrons in the energy interval (E, E + dE) the slowing down density past the energy E_f is q (r, E $\rightarrow$ E_f)

$\therefore$ Total slowing down density for the source neutrons $= q(r, E_f) = \int_{E_f}^{\infty} S(E)\, q(r, E \rightarrow E_f)$

(3)

$$\therefore \tau(E_f) = 1/6 \int_0^{\infty} r^4 q(r, E_f)\, dr \Big/ \int_0^{\infty} r^2 q(r, E_f)\, dr \qquad (4)$$

$$= \frac{1}{6} \frac{\int_0^{\infty} \int_{E_f}^{\infty} r^4 S(E)\, q(r, E \rightarrow E_f)\, dE\, dr}{\int_0^{\infty} \int_{E_f}^{\infty} r^2 S(E)\, q(r, E \rightarrow E_f)\, dE\, dr} \qquad (5)$$

For an infinite medium with no absorption

$$\int_0^{\infty} \int_{E_f}^{\infty} 4\pi r^2 q(r, E \rightarrow E_f)\, S(E)\, dE\, dr = S \qquad (6)$$

where S = source intensity $= \int_0^{\infty} S(E)\, dE$

Substituting (6) in (5) we get

$$\tau(E_f) = \frac{1}{6} \int_0^{\infty} \int_{E_f}^{\infty} r^4 S(E)\, q(r, E \rightarrow E_f)\, dE\, dr/(S/4\pi)$$

$$= \frac{2\pi}{3S} \int_0^{\infty} \int_{E_f}^{\infty} r^4 S(E)\, q(r, E \rightarrow E_f)\, dE\, dr$$

$$= \frac{1}{S} \int_{E_f}^{\infty} S(E)\, \tau(E - E_f)\, dE \qquad (7)$$

where $$\tau(E \rightarrow E_f) = \frac{1}{6} \frac{\int_0^{\infty} r^4 q(r, E \rightarrow E_f)\, dr}{\int_0^{\infty} r^2 q(r, E \rightarrow E_f)\, dr} \qquad (8)$$

$$= \frac{2\pi}{3} \int_0^{\infty} r^4 q(r, E \rightarrow E_f)\, dr$$

Hence the age of neutrons for an energy distributed source is some average value of the individual ages of monoenergetic neutrons over the source spectrum.

If a foil is kept at a particular distance r from the neutron source in a moderator, the activity of the foil is given by

$$A(r) = \int_0^\infty V N_f \sigma_{af}(E) \phi(r, E)\, dE \qquad (9)$$

where V = volume of the foil

N_f = Atom density of the foil

σ_{af} = Microscopic absorption cross section of the foil

$\phi(r,E)dE$ = flux of neutrons at a distance r, from the source and in the energy interval E and E + dE

As the age diffusion approximation, it may be assumed that

$$q(r, E) = \xi \Sigma_s(E) \phi(r, E)\, dE \qquad (10)$$

where ξ = Average logarithmic energy decrement per collision

$\Sigma_s(E)$ = Macroscopic scattering cross section of the medium at energy E.

Substituting (10) in (9)

$$A(r) = V N_f \int_0^\infty \sigma_{af}(E) \frac{q(r, E)\, dE}{\xi \Sigma_s(E) E} \qquad (11)$$

Using a cadmium covered foil, all thermal neutrons can be eliminated and prevented from reaching the foil. If the foil has a high resonance peak then,

$$A(r) \approx V N_f \int_{res.} \sigma_{af}(E) \frac{q(r, E)\, dE}{\xi \Sigma_s(E) \cdot E}$$

$$= V N_f\, q(r, E_{res.}) \int_{res.} \frac{\sigma_{af}(E)\, dE}{\xi \Sigma_s(E) . E} \qquad (12)$$

It is assumed here that the slowing down density $q\ (r,\ E_{res.})$ is constant over the resonance.

Substituting for $q\ (r,\ E_{res.})$ from (12) into (2), the useful expression for experimental age determination is obtained as

$$\tau(E_s \rightarrow E_f) = \frac{1}{6} \int_0^{\infty} A\ (r)\ r^4\ dr \Big/ \int_0^{\infty} A\ (r)\ r^2\ dr \qquad (13)$$

The final energy E_f corresponds to the energy of a resonance level, usually above the thermal energy such as Indium resonance energy (1.46 ev). The age to thermal energy cannot be determined as it is not possible to distinguish between the neutrons which are just thermalized and those which have been diffusing for some time after they are thermalized.

2.2 Foil activation by irradiation

The activity of an isotope on irradiation by neutrons cannot be measured, but the number of radioactive particles emitted by the product isotope in a period of time can be counted. This quantity is in turn related to the activity $A\ (r)$ of the primary isotope.

Suppose a primary isotope with number of nuclei per unit volume equal to N_1 (in a foil form) is irradiated by neutrons in a moderating medium at a distance r from a point source located in the medium, for a time t_o and the product nuclide formed is radioactive with λ as the decay constant. Let the

foil activity be counted starting from a time t_2 until a time t_3, both t_2 and t_3 being measured from the time the irradiation is stopped. Then the decay rate equation for the product nuclide with the number of nuclei surviving at time t, equal to N_2 is given by the following equations :

During irradiation

Rate of change of number of product nuclei

= Rate of formation - Rate of decay.

$$\frac{d N_2}{dt} = V \int_0^\infty N_1 \sigma_{af} (E) \phi (r, E) dE - \lambda N_2 \tag{14}$$

Where N_1 is the atom density of the primary isotope, V is the volume of the foil and σ_{af} (E) is the activation cross section of the primary isotope.

$$\therefore N_2 = \frac{V}{\lambda} N_1 \int_0^\infty \sigma_{af} (E) \phi (r, E) dE (1 - e^{-\lambda t})$$

$$= \frac{A (r)}{\lambda} (1 - e^{-\lambda t}) \tag{15}$$

$\therefore$ Activity of the product nuclide at the end of irradiation $= A(r) (1 - e^{-\lambda t_0})$ (16)

After irradiation

Rate of change of number of product nuclii = - Rate of decay

$$\frac{d N_2}{dt} = - N_2 \lambda$$

At $t = 0$, $N_2 = \frac{A(r)}{\lambda}(1 - e^{-\lambda t_o})$

$$\therefore N_2 = \frac{A(r)}{\lambda}(1 - e^{-\lambda t_o})\, e^{-\lambda t} \tag{17}$$

Activity of the product nuclide at time 't' after irradiation $= A(r)(1 - e^{-\lambda t_o})\, e^{-\lambda t}$ (18)

The variation of activity both during irradiation and after irradiation is shown in Fig. 1.

Total number of counts in time interval $(t_2 - t_1)$ $= \int_{t_1}^{t_2} A(r)(1 - e^{-\lambda t_o})\, e^{-\lambda t}\, dt$

$$= \frac{A(r)}{\lambda}(1 - e^{-\lambda t_o})(e^{-\lambda t_1} - e^{-\lambda t_2}) \tag{19}$$

If C is the number of counts recorded by a detector in time $(t_2 - t_1)$ and B is the background counts during this time, then

$$(C - B) = \frac{A(r)}{\lambda}(1 - e^{-\lambda t_o})(e^{-\lambda t_1} - e^{-\lambda t_2})$$

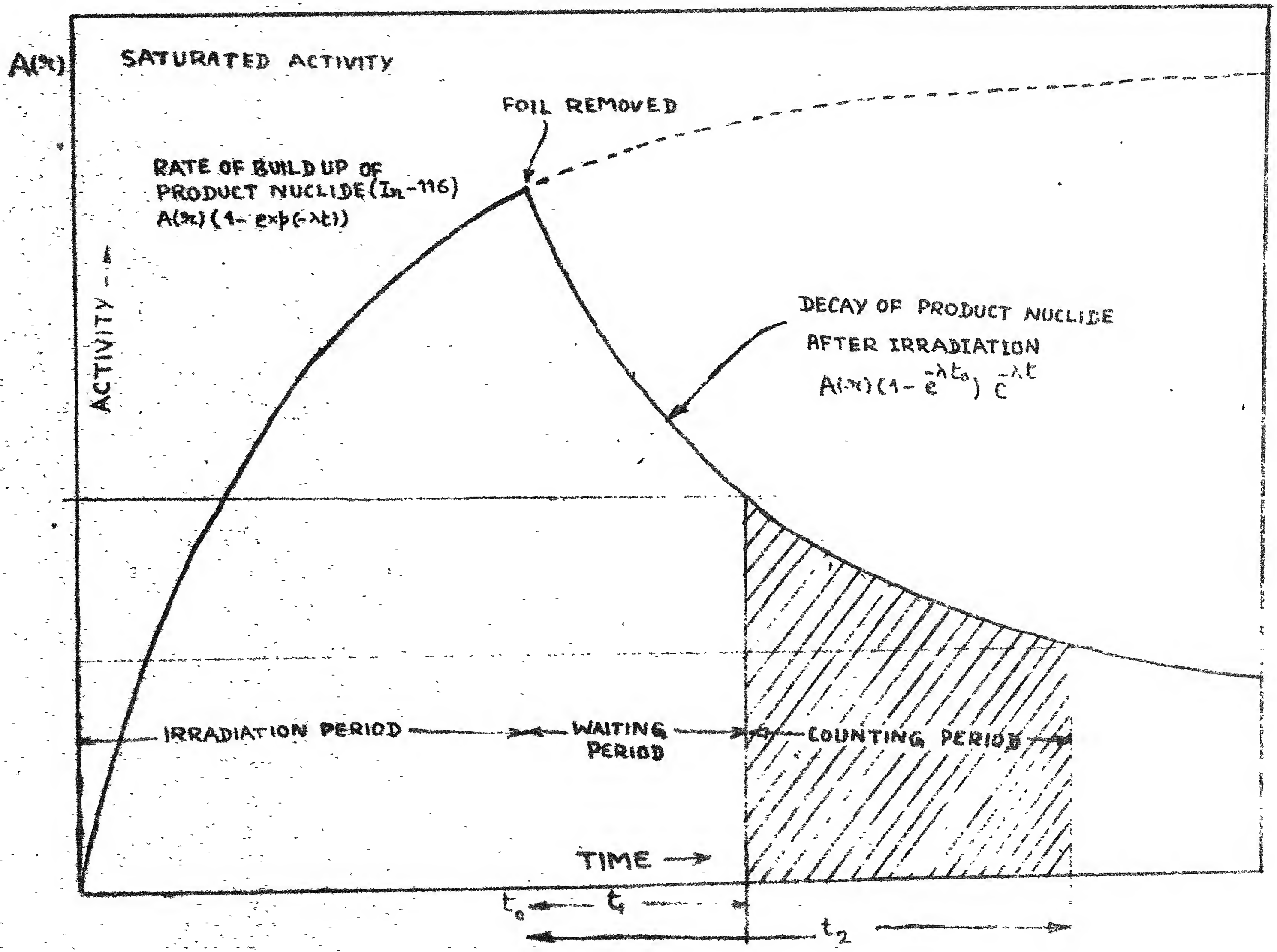
$$\therefore A(r) = (C - B)\lambda \,/\, (1 - e^{-\lambda t_o})(e^{-\lambda t_1} - e^{-\lambda t_2}) \tag{20}$$

The activities of irradiated foils are calculated from equation (20).

2.3 Activities of Indium

Natural Indium foils containing 95.77% Indium - 115 and

FIGURE 1: FOIL ACTIVITY VERSUS TIME CURVE DURING AND AFTER IRRADIATION



23% of Indium - 113, are proposed to be used in the experi-
nt. The decay modes of the isotopes of Indium are analyzed
low. Both Indium - 113 and Indium - 115 acquire activities
der neutron irradiation.

dium - 113 activities

1) $${}^{113}_{49}\mathrm{In} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{113\,m}_{49}\mathrm{In} + {}^{1}_{0}\mathrm{n}\,;\quad {}^{113m}_{49}\mathrm{In} \xrightarrow{99.8m} {}^{113}_{49}\mathrm{In}$$

2) $${}^{113}_{49}\mathrm{In} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{114}_{49}\mathrm{In} \xrightarrow{72s} {}^{114}_{50}\mathrm{Sn}$$

(3) $${}^{113}_{49}\mathrm{In} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{114\,m}_{49}\mathrm{In} \xrightarrow{49d} {}^{114}_{49}\mathrm{In} \xrightarrow{72s} {}^{114}_{50}\mathrm{Sn}$$

Indium - 115 activities

(4) $${}^{115}_{49}\mathrm{In} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{116}_{49}\mathrm{In} \xrightarrow{13.4s} {}^{116}_{50}\mathrm{Sn}$$

(5) $${}^{115}_{49}\mathrm{In} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{115\,m}_{49}\mathrm{In} + {}^{1}_{0}\mathrm{n}\,;\quad {}^{115m}_{49}\mathrm{In} \xrightarrow{4.5h} {}^{115}_{49}\mathrm{In}$$

(6) $${}^{115}_{49}\mathrm{In} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{116\,m_1}_{49}\mathrm{In} \xrightarrow{54m} {}^{116}_{49}\mathrm{In} \xrightarrow{13.4s} {}^{116}_{50}\mathrm{Sn}$$

(7) $${}^{115}_{49}\mathrm{In} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{116\,m_2}_{49}\mathrm{In} \xrightarrow{2.16s} {}^{116}_{49}\mathrm{In} \xrightarrow{13.4s} {}^{116}_{50}\mathrm{Sn}$$

Because of the small fraction of In^{113} present, the activities due to In^{113} are negligible. By counting the foils

10 minutes after irradiation, the activities with 13.4 sec. and 2.16 sec. half lives are eliminated. The 4.5 hour activity is mainly due to high energy neutrons for which the cross section is negligibly small compared to the resonance cross section[13]. Hence after irradiating an Indium foil for about 8 hours and measuring the activity 10 minutes after irradiation, the activity due mostly to the 54.0 minute activity is measured. Hence using this half life time, the resulting activities of the foils can be calculated using equation (20).

CHAPTER III

EXPERIMENTAL SET UP & PROCEDURE

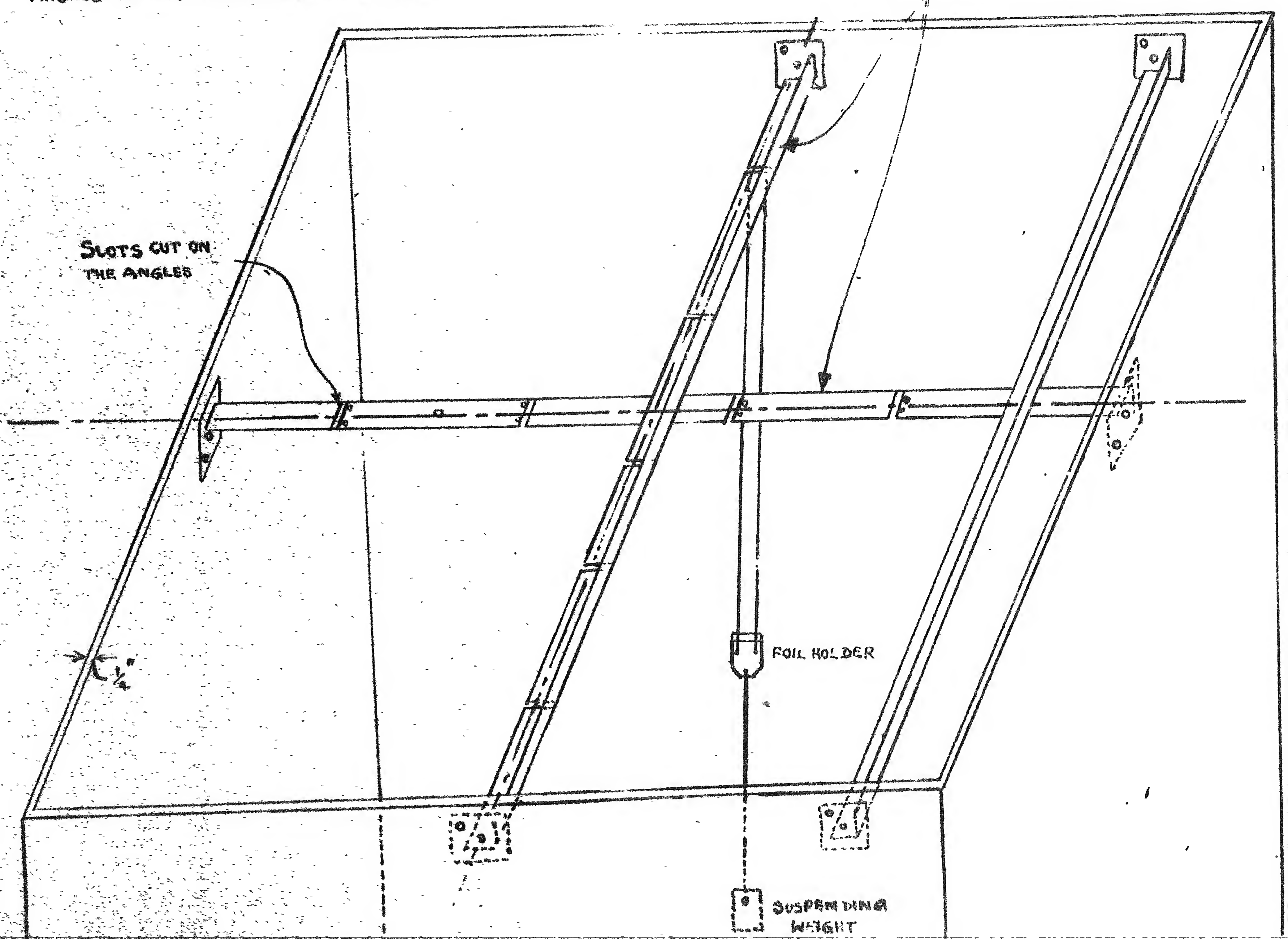
3.1 Description of the experimental set up

In neutron age determination experiments the neutron flux at a point can be either determined by foil activation or by measuring the flux directly by a neutron sensitive detector. Highly pure foils were available and hence foil activation method was chosen. In any age determination experiment using the foil activation method, the following equipment are needed. A tank for containing the moderating medium, an arrangement for suspending the foil holders and source holder, an arrangement to hold the foils and source, the medium and the counting set up. The detailed description of each apparatus and the reason for its selection is given below :

Aluminum Tank and Foil Suspending Arrangement

The moderating medium for age determination, i.e., water is contained in an Aluminum tank of 122 cms x 122 cms x 122 cms size, which was fabricated at H.A.L Kanpur, with 6.35 mm thick plates using Argon arc welding. Aluminum was used mainly to overcome the troubles due to corrosion and the radioactivity that the tank may acquire due to long exposures to neutrons. Three chromium plated mild steel angles were fixed at the top of the tank as shown in Fig. 2. The Pu - Be neutron source was suspended by a nylon thread from the center of the tank

FIGURE 2: TOPVIEW SHOWING ARRANGEMENT OF ANGLES ON THE AGE MEASUREMENT TANK



through a hole made at the central point of the angle. Also, provision was made for suspending foil holders by nylon threads.

The effects of moderator displacement and flux perturbation at a foil position extends upto a certain distance from the foil. If a second foil is kept within such a distance from the first foil, the above effects of the first foil influence the flux at the position of the second foil and is called the shadowing effect. Campbell et. al.[13] have experimentally found that the shadowing effect of foil is negligible when the separation distance between foils is about 10 cms. Hence care was taken to see that in no case the distance between two foils is less than 10 cms.

The foil holders and the source holder were made of Perspex (Lucite). Randall et. al.[17] found that there will be no flux perturbation caused by introducing a material in a medium when the material has the same value of moderating ratio as the surrounding medium. Perspex is the trade name for Methyl Methacrylate with the chemical formula $CH_2 : C\ (CH_3)\ COOCH_3$.[29] It is also known as Lucite or Plexi glass. It has a specific gravity of 1.18. The moderating ratio for Perspex is 153.6 while for water the moderating ratio is 147. Hence the perturbation of flux by Lucite in pure water is negligible.

The foil holders were kept in position by small lead weights suspended by a nylon thread of 36.8 cms long from the

bottom of the foil holder. All the foil holders were fixed at a depth of 67.5 cms from the level of the angles. Thus the centers of the foils and the physical center of the source were in one plane. The contamination by dust etc. of the pure water in the tank was prevented by closing the tank with a cover made of mild steel frame and Aluminum sheet. The sketch of the cover is shown in Fig. 3. This cover contained a few slits through which the foil holders can be pulled out of the tank so that the irradiated foils can be taken out for counting. The slits can be closed tightly by Aluminum covers with rubber gaskets.

Foils and Foil Holders

Cadmium covered Indium foils were used in the experiment. The cadmium cover sets were 0.611 mm thick and 16.215 mm diameter. The Indium foils were 0.254 mm thick (184.9 mg/cm^2) and 12.7 mm diameter. The foils were pure Indium containing 95.77% In^{115} and 4.23% In^{113}. Indium foils were used because it has a high activation cross section and the associated activities are practically feasible for measurement. As foil holders were not readily available they were designed and made out of Perspex in the Precision Shop. As the experiment was performed both with bare Indium foil and cadmium covered Indium foil, two separate sets of foil holders were made. The size and shape of these two foil holders are shown in Figs. 4 and 5. The cadmium covered Indium foils were first enclosed in Perspex foil holders and then suspended in the tank.

FIGURE 3 TOP COVER FOR THE AGE MEASUREMENT TANK

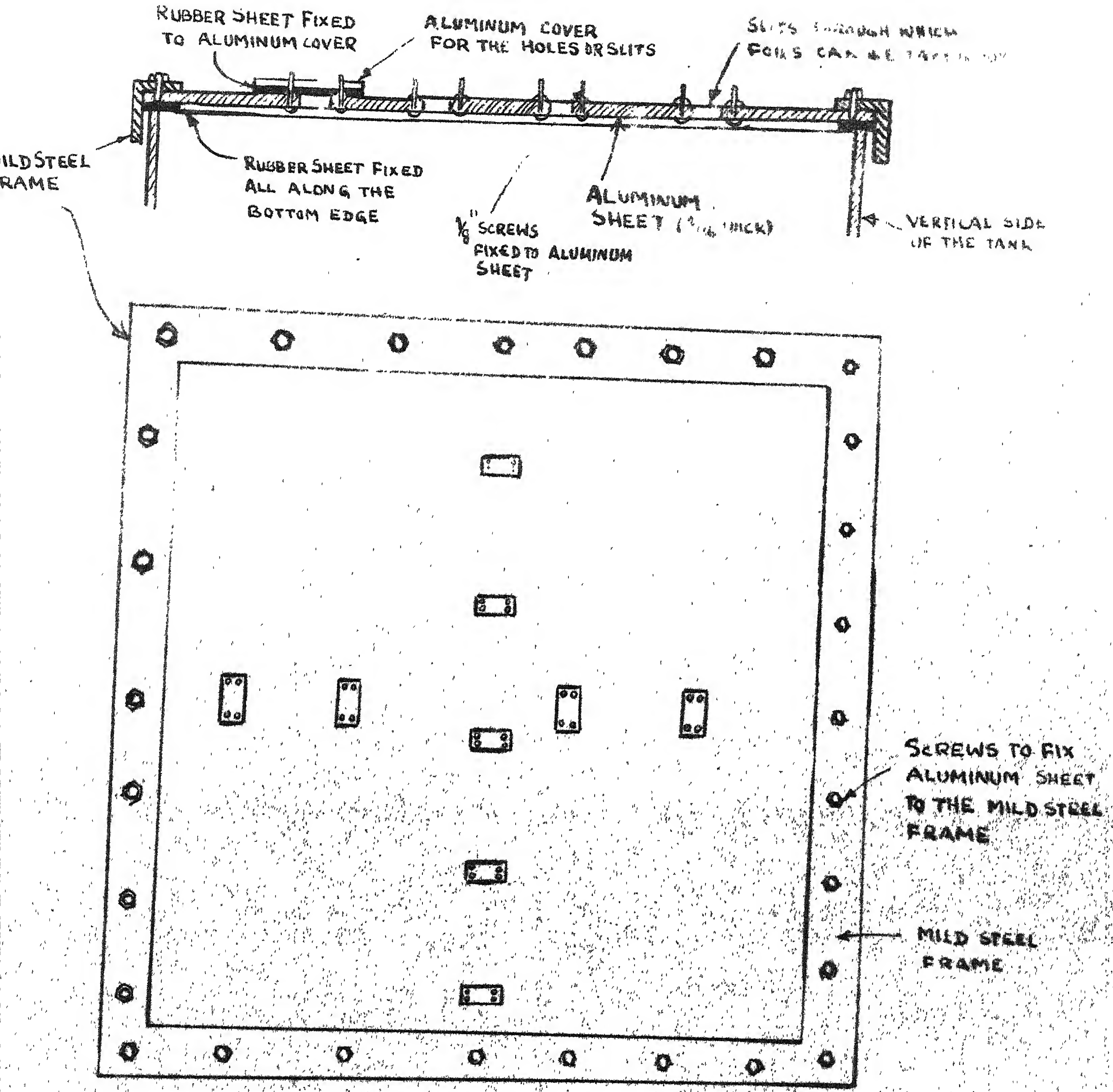
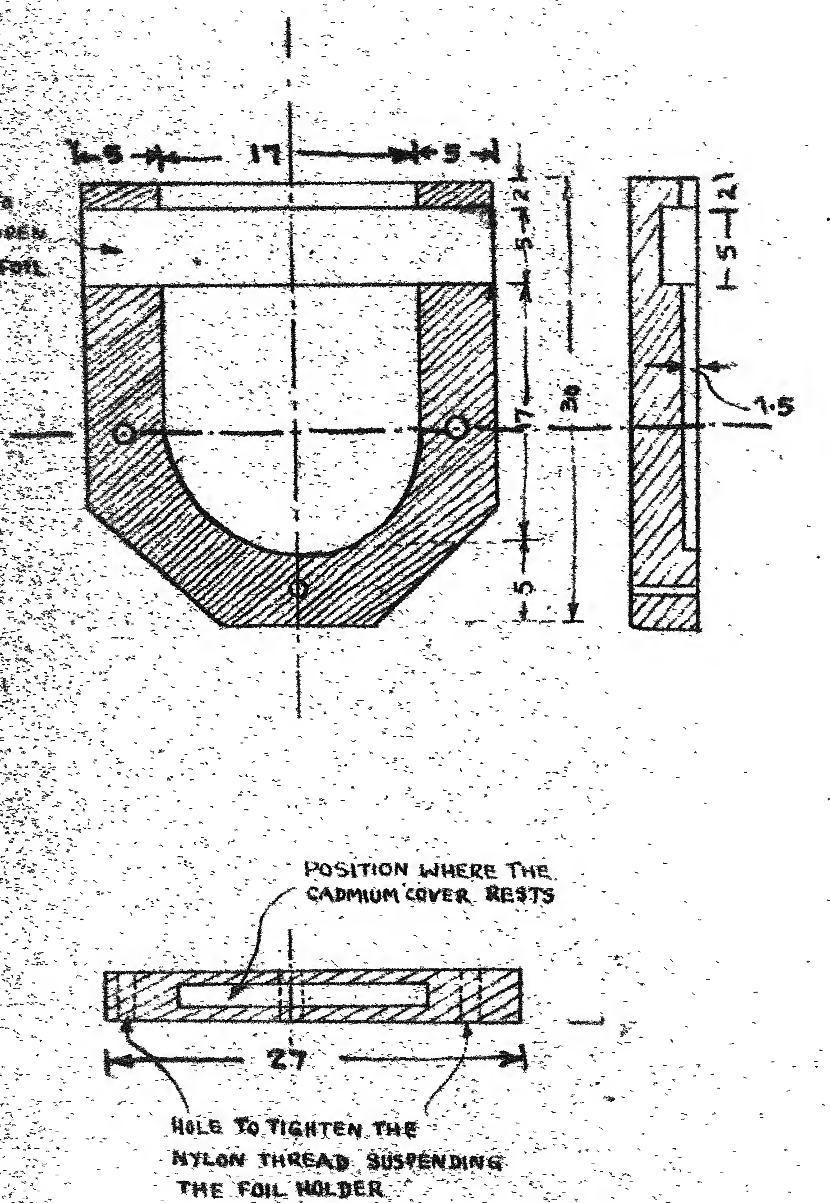
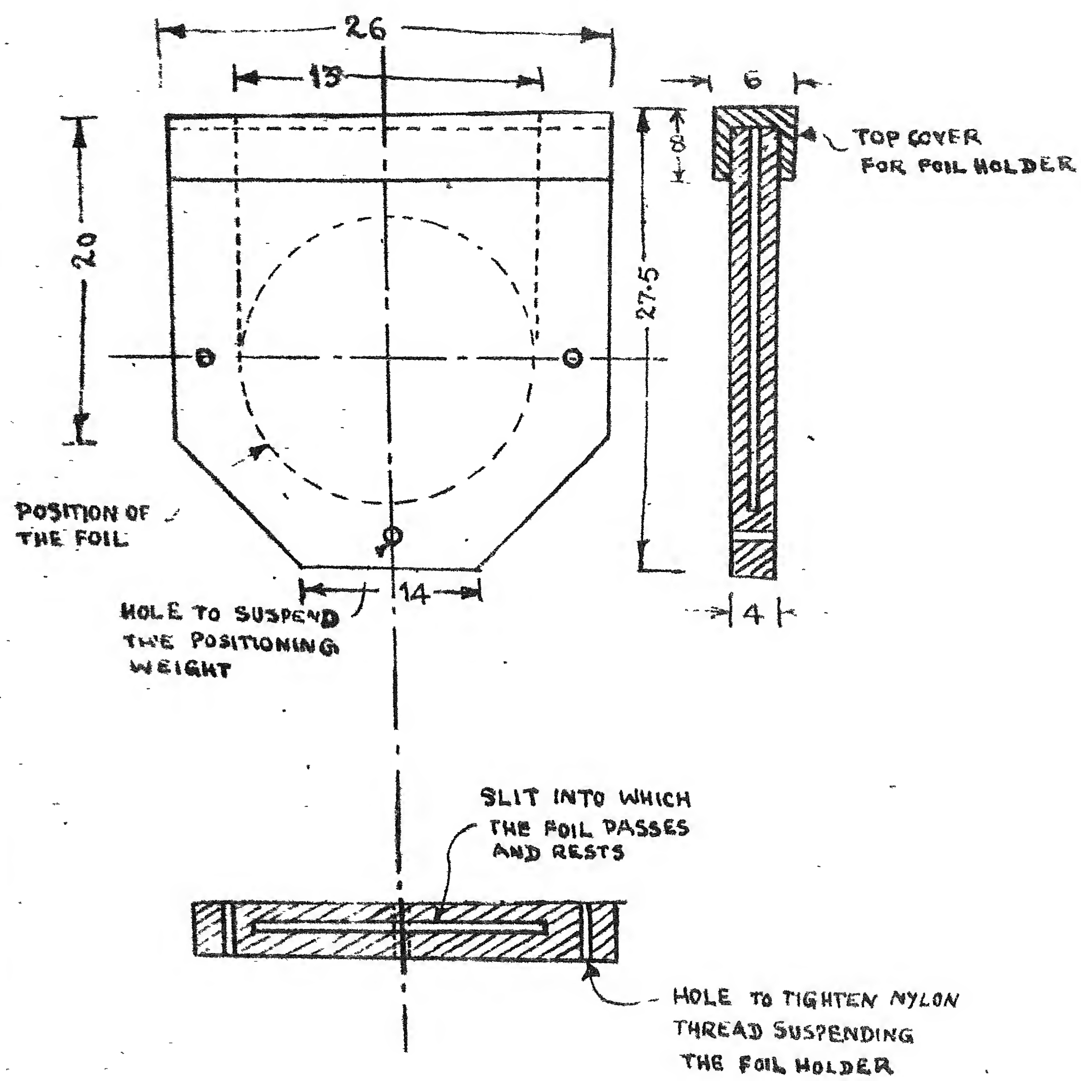


FIGURE 5: PERSPEX FOIL HOLDER FOR CADMIUM COVER SET



ALL DIMENSIONS ARE IN MILLIMETERS

FIGURE 4 : FOIL HOLDER FOR BARE INDIUM FOILS



ALL DIMENSIONS ARE IN MILLIMETERS

Source and Source Holder

A 5 curie Plutonium-Beryllium neutron source obtained from Bhabha Atomic Research Centre, Trombay was used in this experiment. As it has a steel cylindrical cover without any holding device, it had to be enclosed in a source container made of Perspex material, which in turn could be suspended in water by a nylon thread. The size and shape of this Perspex source holder is as shown in Fig. 6. The suspension arrangement for this source holder is also shown in Fig. 7.

The Pu - Be neutron source is an energy distributed source with a characteristic spectrum as shown in Fig. 8. It's average energy is 4.5 Mev. The source is cylindrical with 5.334 cms diameter and 7.3 cms height. The half life of the source is 24,300 years and so can be assumed to be a steady source. But Jordan et. al.[19] have shown that the emission rate of a Pu - Be source increases with time depending upon the amount of Pu^{241} present during fabrication of the source. But of course this will not affect the age measurements since significant increase in the emission rate can be observed only after periods of about a year.

Pure Light Water

For conducting the experiment, pure water is needed. Tap water had a conductivity of about 1000 micro mhos/cm and so it had to be purified to a considerable extent. The

FIGURE 6: PERSPEX SOURCE HOLDER

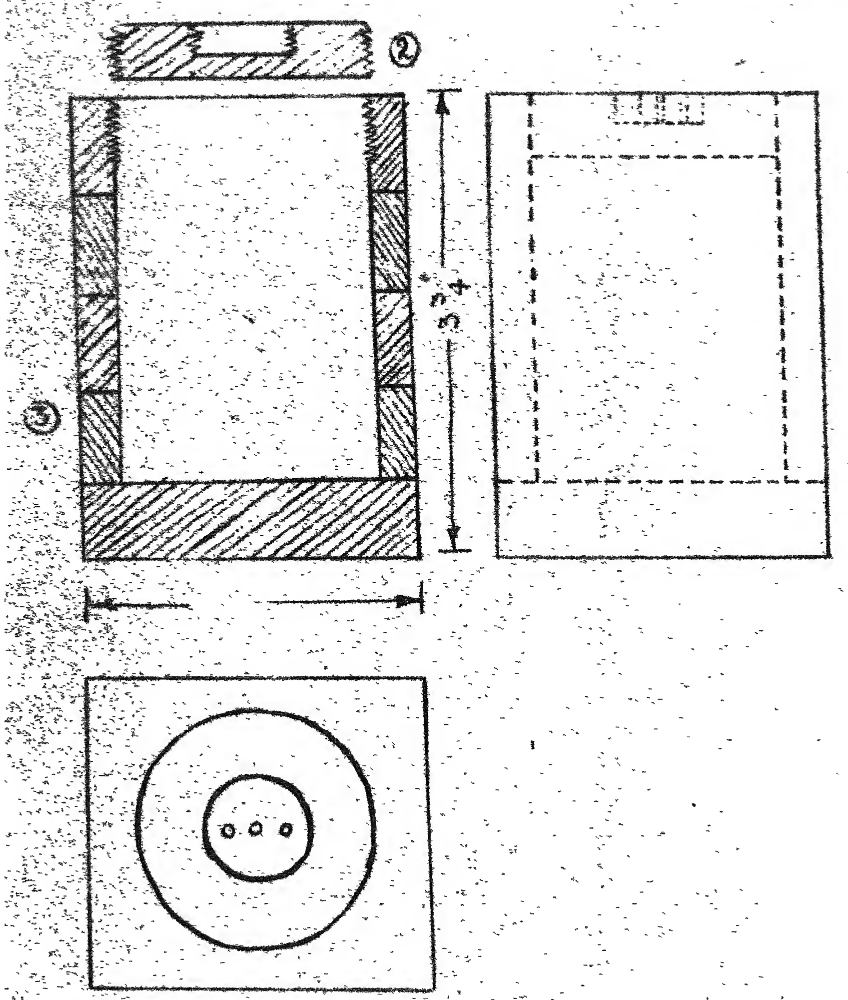
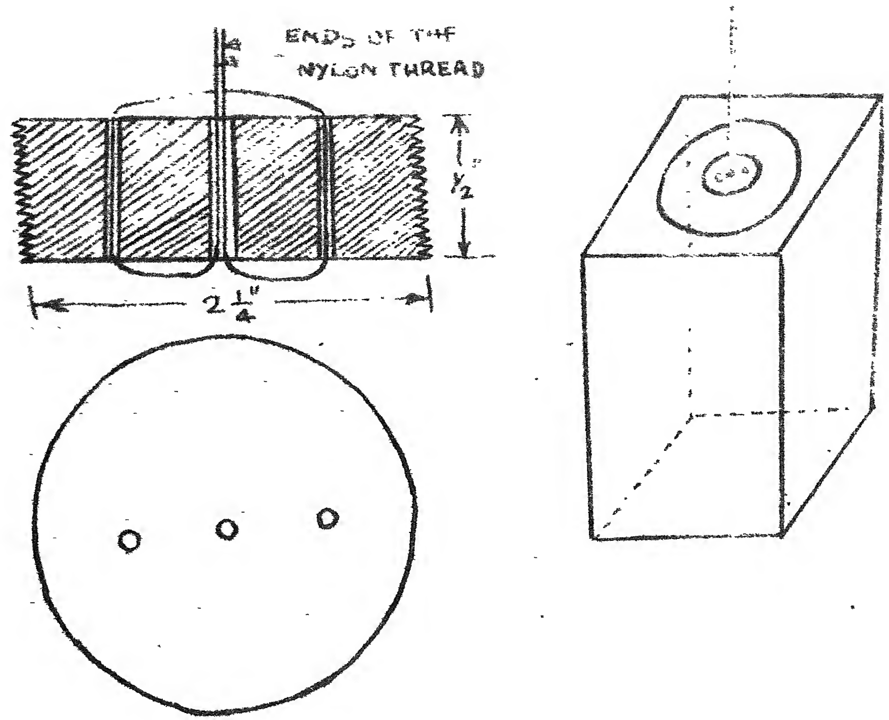
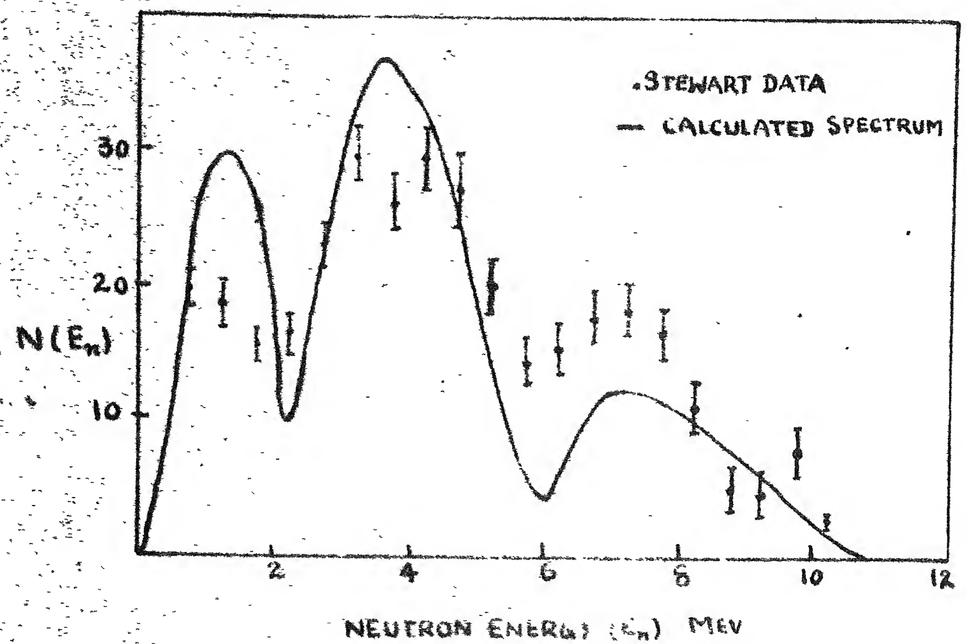


FIGURE 7: METHOD OF SUSPENDING THE SOURCE HOLDER



PART 1 OF FIGURE 6 EXPANDED ABOVE

FIGURE 8: CALCULATED AND MEASURED NEUTRON SPECTRUM FOR A Pu-α-Be NEUTRON SOURCE



REFERENCE: W.N. HESS, ANNALS OF PHYSICS, VOLUME 2, p. 115 (1959)

analysis of the tap water is shown in table 4.

TABLE 4

CHEMICAL ANALYSIS OF TAP WATER

CONSTITUENT	QUANTITY IN p.p.m.
Total dissolved solids	500 to 600
Total hardness	210
Calcium hardness	193
Magnesium hardness	17
Iron	0.8 as Fe
Sulphates	35
Dissolved Oxygen	6.4 at 35°c
Residual chlorine	0.5 as cl_2
Ph : 8.2	

The tap water on distillation showed a conductivity of about 20 micro mhos/cm. It was found that the conductivity of tap water could be reduced to 0.1 micro mhos/cm by passing it through a four column demineralizer plant. Hence it was decided to use demineralized water. As the demineralizer plant was installed for the first time, it had to be regenerated twice so as to get water with low conductivity. After collectint a bout 1100 litres of demineralized water the measured conductivity of the water was 0.7 micro mhos/cm. Earlier 300 litres of distilled water was passed through another demineralizer and the measured conductivity of this water was

less than 0.1 micro mhos/cm. This water was also stored in the tank. The resulting mixture of these ~~x~~ two showed a final conductivity of 0.2 micro mhos/cm during the experiment.

The demineralizer obtained from the I.A.E.C. company consists of an active carbon filter column, one anion exchange column and another mixed bed column. The chemical analysis of the water used in the experiment was done by the photometric method using the Hellige Aqua Tester which is a water analysing apparatus. The total dissolved solids in the water used in the experiment was 1.6 mg/litre. Chemical analysis was done for Lead, Cadmium, Manganese, Sulphides, Chromates and Copper and each one of these was found to be much less than 0.1 parts per million.

Counting Set Up

The schematic diagram of the G.M. counting set up is as shown in Fig. 9. The pulses from the G.M tube are first passed through the quenching tube. The pulses produced by the undesirable electrons liberated from the cathode of the tube by the interaction of gamma rays are quenched in the quenching tube. The output pulses from the quenching tube are counted by the scaler. The time period of counting is controlled by the setting of the timer. The G.M. tube with the foil holder stand is kept inside a Lead castle to reduce the background of the counting system.

The schematic diagram of gas flow proportional counting system is shown in Fig. 10. The counting gas used for the gas flow proportional detector is Indane. The Indane gas was dried by passing it through Ca So_4 column before letting it into the detector. The output pulses from the detector are amplified in a preamplifier and then the final amplification is done by the non overload amplifier. The output pulses from the linear non overload amplifier are counted by the scaler, the counting duration of which is in turn controlled by the timer.

The difficulties in the counting set up were due to its unreliable performance. First the Amperex Beryllium window proportional detector was tried but did not have a good plateau. The plateau is a characteristic curve of the detector showing the dependence of count rate upon the high voltage applied to the detector. The flattest portion of this curve is called the plateau region and the percentage change in the count rate per 100v change in the high voltage is the characteristic parameter of the plateau. Though the gas flow proportional counting system has about 1% plateau, it is not consistent and stable. The plateau for the Gas flow proportional counting system was obtained using a Uraniam Oxide source which was made in the laboratory. But the detector cannot be used for activities with small half lives since a minimum time of about 8 minutes is needed for flushing the

FIGURE 9: GEIGER MULLER COUNTING SET-UP

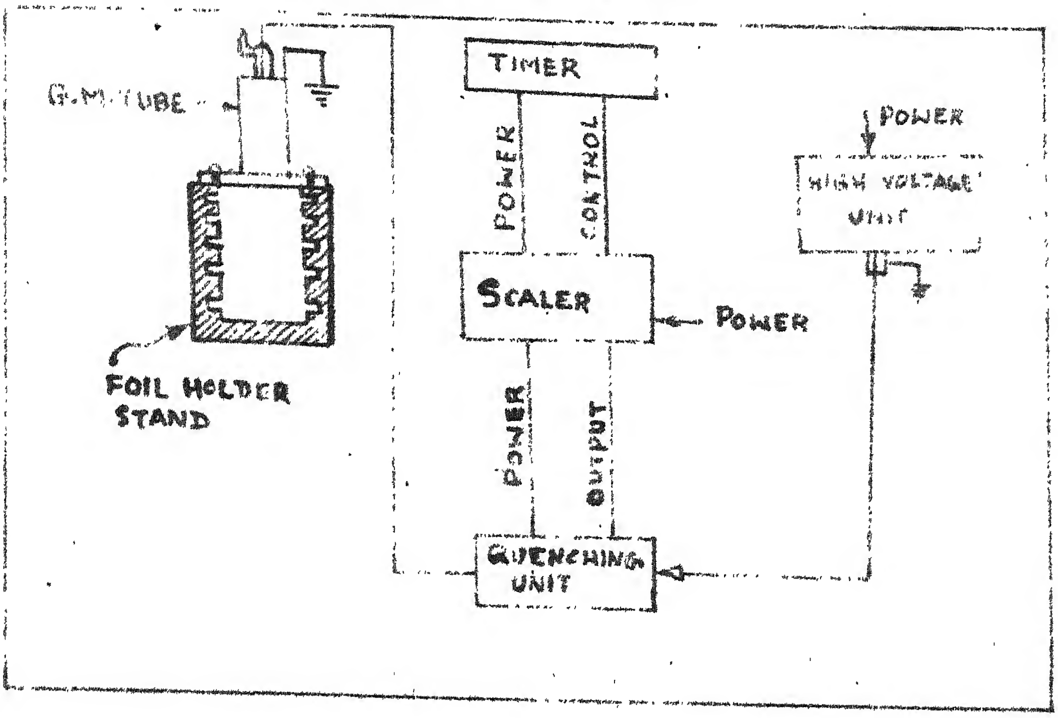
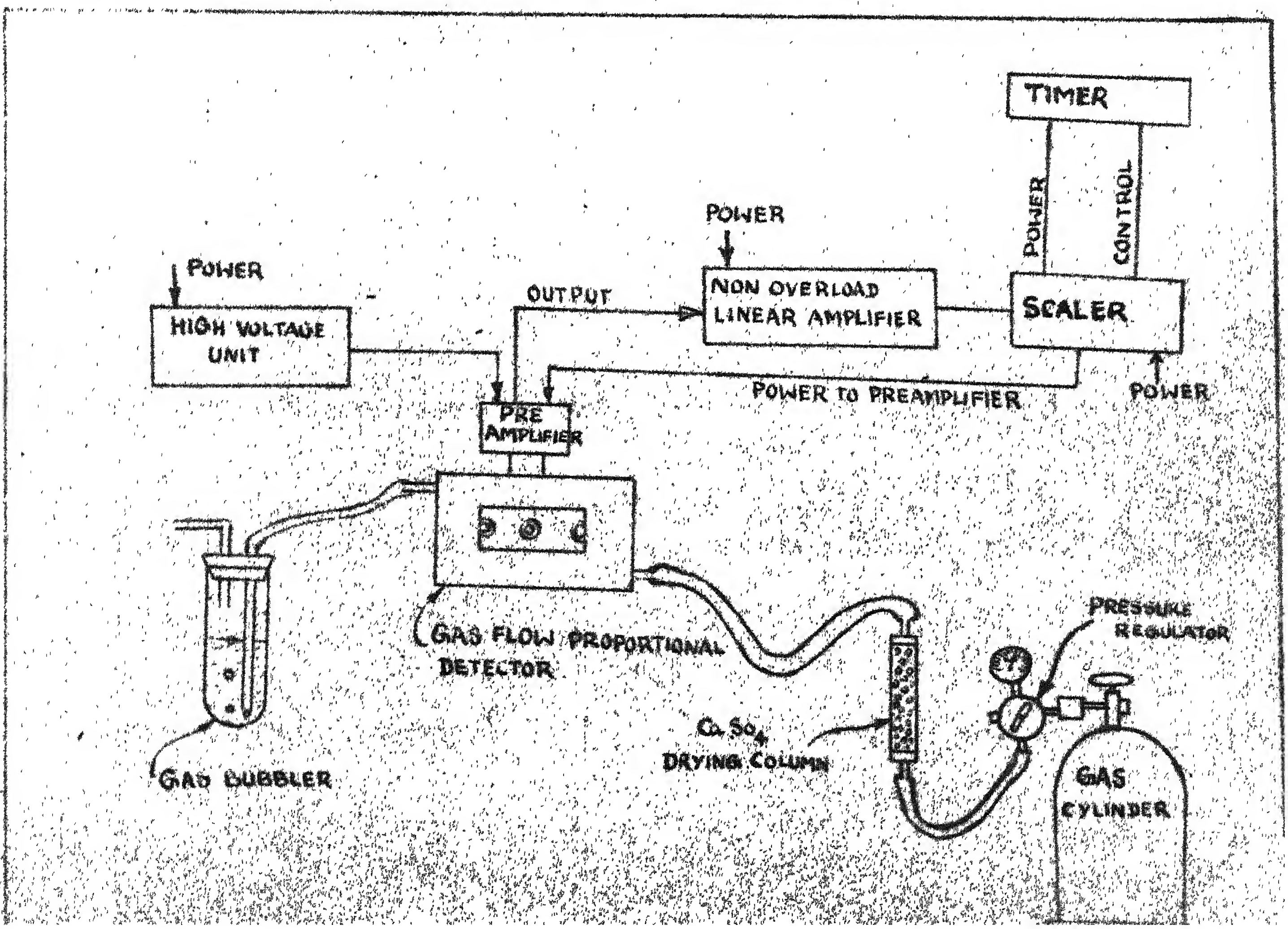


FIGURE 10: WINDOWLESS GAS FLOW PROPORTIONAL DETECTOR SYSTEM

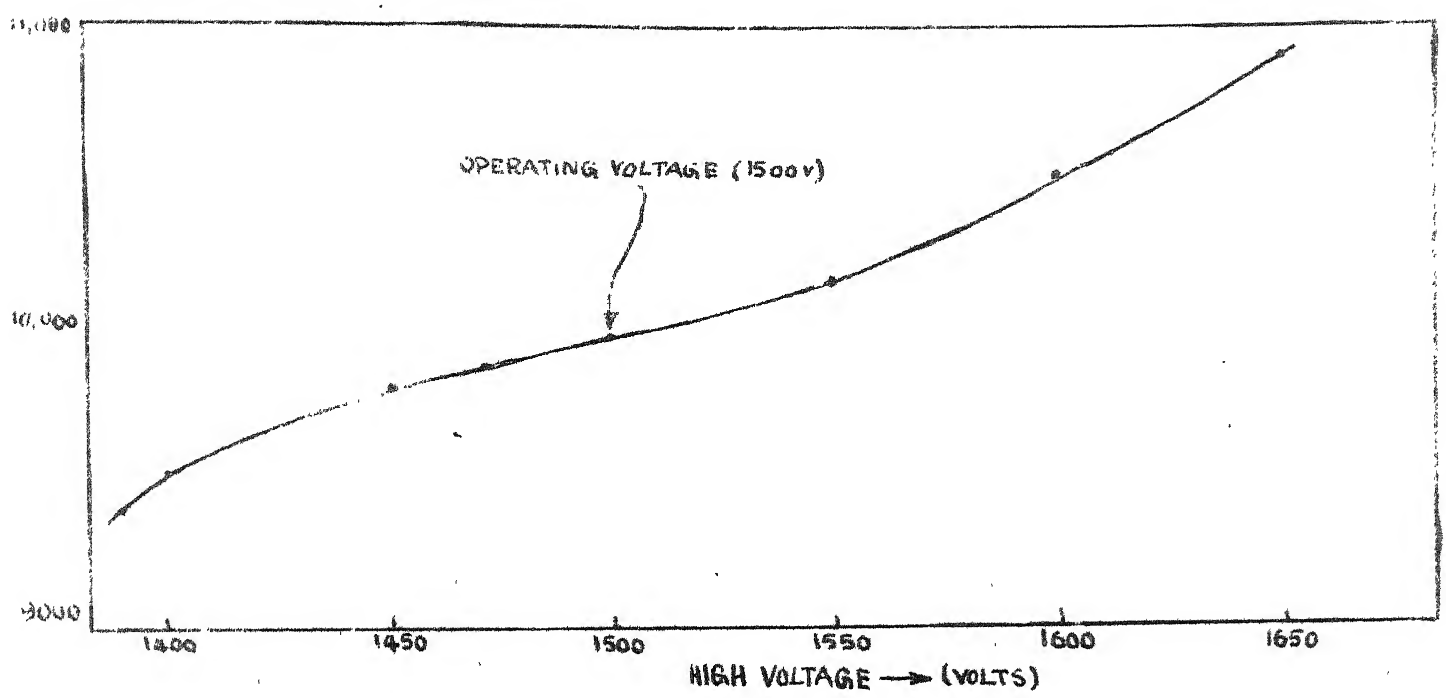


detector system with the gas and for voltage stabilization after the sample is introduced into the detector. The plateau of the gas flow proportional detector is shown in Fig. 11. The G.M. counting set up exhibited good stability and reliability but it has only 4% to 5% plateau. Hence G.M. counting set up along with a highly stabilized high voltage regulated power supply (John Fluke) was used. The plateau characteristic of the G.M. counting set up is shown in Fig. 12. The plateau of the G.M. set up was obtained using the $Sr^{90} - Y^{90}$ Beta standard source, supplied by the BARC, Trombay. The operating voltage was selected as 1500v and the background count rate of this system is about 50 - 60 counts per minute, without any shielding around the G.M. tube. With the G.M. tube inside a lead castle, the background varied from 6 cpm to 20 cpm.

Source Container

Another cylindrical source container with good neutron shielding was also made. The source was kept inside this container when it was not being used for an experiment. This cylindrical container has an Aluminum box in the centre to hold the source. Surrounding this is an 20 cms thick annular paraffin wall. The paraffin wall is surrounded by a layer of boric acid powder of about 5 cms thickness. The sketch of this container is shown in Fig. 13.

FIGURE 10: PLATEAU CURVE FOR G.M. COUNTING SET-UP



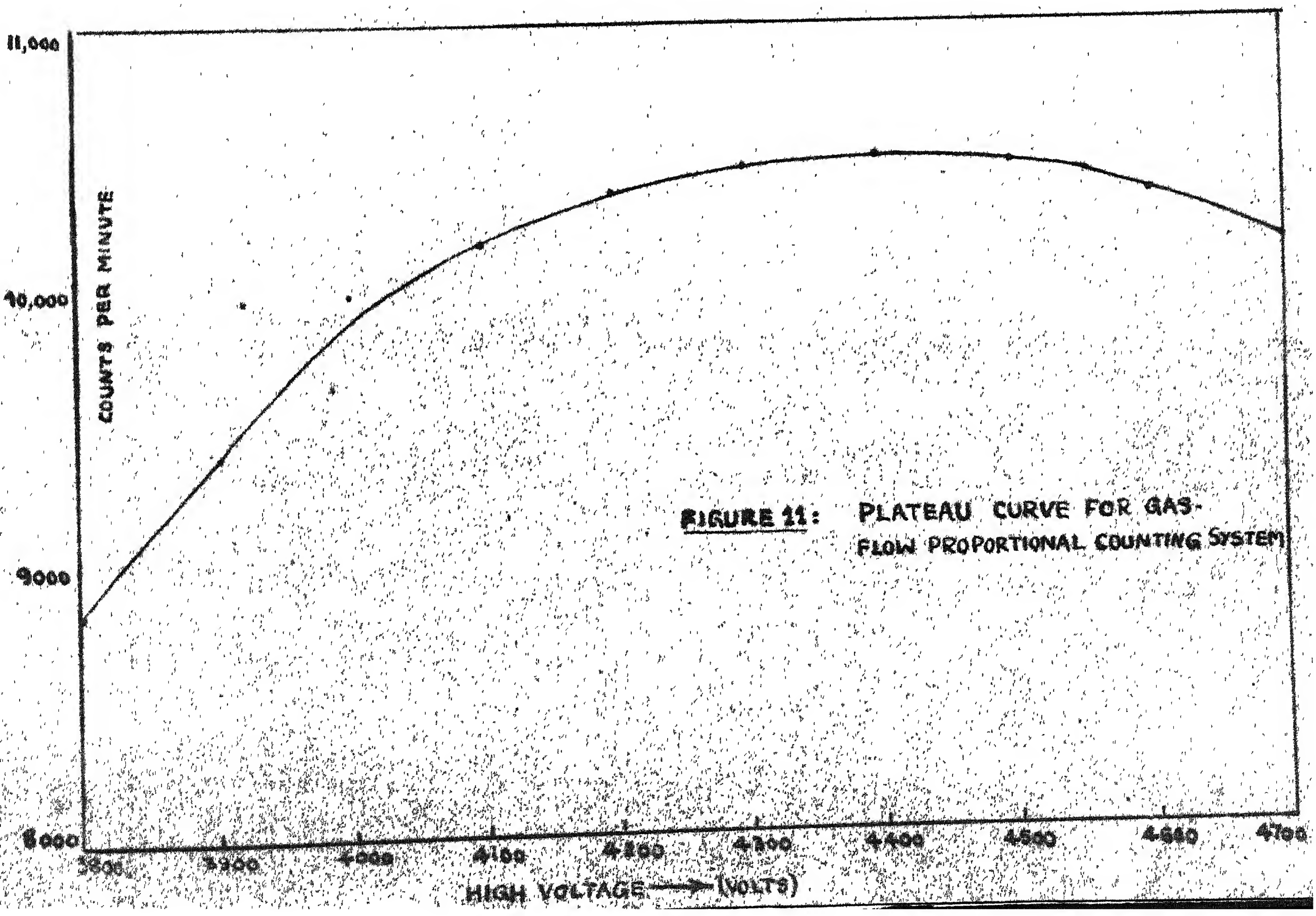
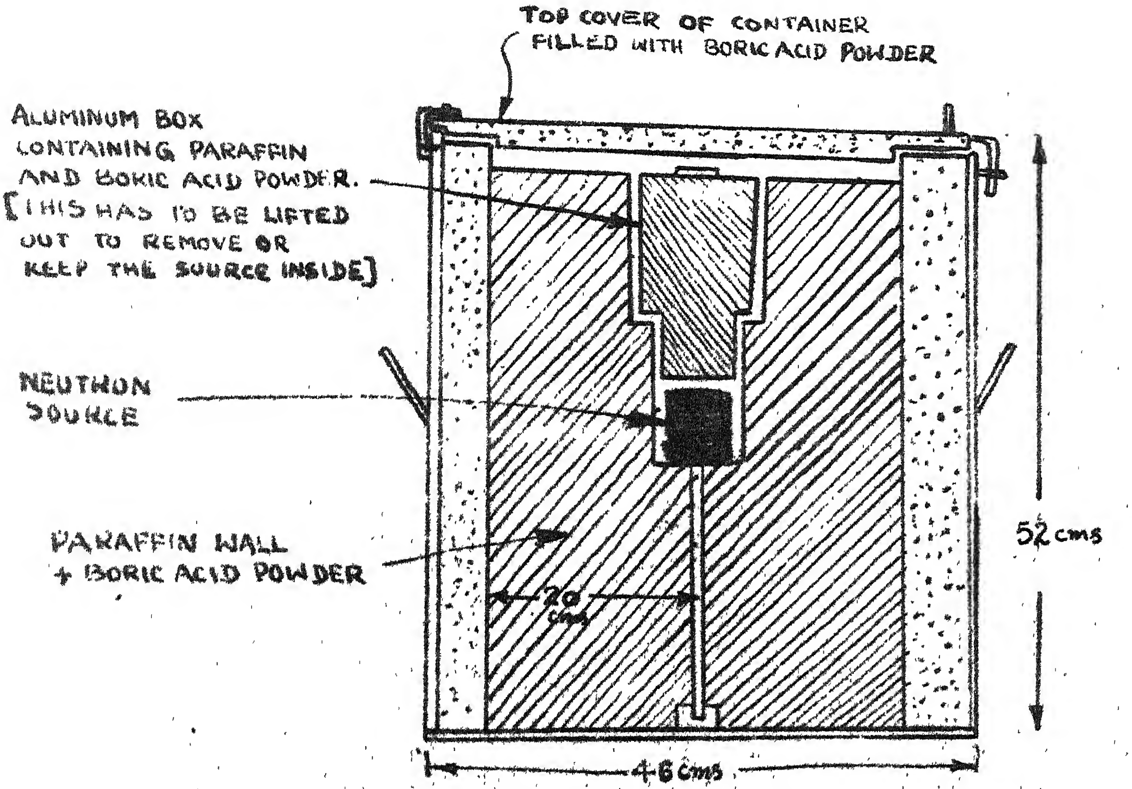
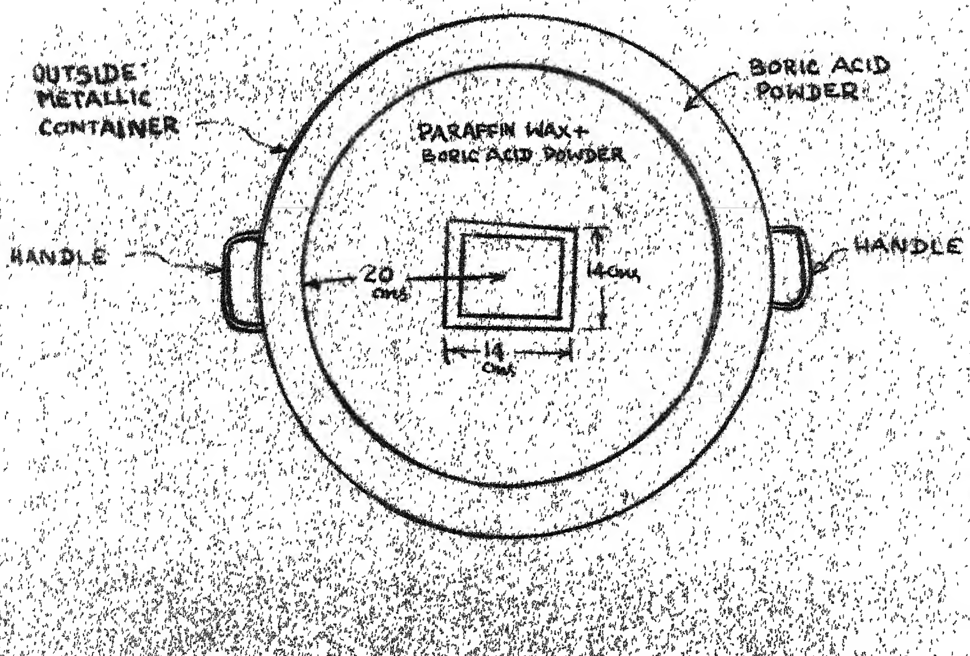


FIGURE 11: PLATEAU CURVE FOR GAS-FLOW PROPORTIONAL COUNTING SYSTEM

FIGURE 13: SHIELDED CYLINDRICAL SOURCE CONTAINER





3.2 Experimental Method

The perspex foil holders were suspended from the angles by the thin nylon threads at 67.5 cms below the level of the angles. The foil holders were kept in position by small lead weights hung from the botton of the foil holder and 14" below it. The source holder was suspended by thin nylon thread at the centre of the tank. The foils were thus kept at intervals of about 2.5 cms starting from 5.45 cms. The thread lengths were so adjusted that the centres of the foils lie in the horizontal central plane of the cylindrical source. The perspex source holder was also suspended by a nylon thread at the centre of the tank. The length of this thread was such that the centre of the source was in the plane of centres of the foils. The tank is closed by a cover and it was filled with the demineralized water upto a depth of about 100 cms. The source was transferred from the shielded source container into the perspex source holder. The neutron flux and other radiations were monitored outside the tank with a neutron - surveymeter and radiation surveymeter and the maximum recorded readings were 5 neutrons/cm^2/sec and 0.5 mr/hr respectively. The foils were lowered into the tank and the time was noted. The distance between any two foils or the distance between a foil and the side of the tank was kept at least 14 cms, which is slightly more than 10 cms. required to eliminate the shadowing effect. When the Indium foil is irradiated for 7 hours the

54 minute activity will develop upto about 99% of the saturation activity as given by equation (20). After irradiating the foil for about 7 hours or greater than 7 hours, the foil was taken out of the tank. The time at which the foil was taken out of the tank is noted and a stop watch is started. Ten minutes after the foil was taken out of the tank, the total activity of the foil was counted with the G.M. counting set up for 10 minutes. Both sides of the foil were counted. This is repeated for all the foils that were suspended at all distances from the source. The experimental data are shown in tables 5, 6 and 7; here distances are in centimeters and times are in minutes.

The experiment was performed for the following three different cases to find out the effects of thermal neutron and high energy neutron activations, on the age value to Indium resonance.

(a) Irradiation of bare Indium foil

(b) Irradiation of cadmium covered Indium foil

(c) Irradiation of cadmium covered Indium covered Indium foil.

CHAPTER IV

CORRECTIONS ON THE EXPERIMENTAL VALUES

Using equation (20) the saturation activities A (r) of the foils at various distances from the source are calculated. The background count rate of the G.M. set up causes an error in the count rate recorded by the activated foil. The flux depression by the foil, the absorption of In resonance neutrons by the cd cover, the finite size of the source and the foil, and the change in the density of the medium are the factors which cause error in the value of the age. The corrections applied for these effects are explained below. The uncorrected activities A (r), A (r) r^2, A (r) r^4 are shown in table 8.

1. Background correction

The background count rate varied from 6 cpm to 20 cpm. Background count rates were recorded several times during the counting and the average value of these readings was taken as the constant background count rate throughout the experiment. The product of the background count rate and the counting time for the foils was subtracted from the observed counts for the foil.

2. Flux depression correction

Since the foil is a good neutron absorber, the flux in the neighbourhood of the foil will be depressed. Hence a

correction factor F_{sp} is used to multiply the observed countrate to get the corrected countrate of the foil. This correction factor given by Tittle[21] is a modification of the original factor obtained by Bothe[20]. It can be written as

$$F_{sp} = 1 + \frac{\alpha}{2} \left(\frac{3\,RL}{(2\,\lambda_{tr})\,(R + L)} - 1 \right) \qquad R \gg \lambda_{tr} \qquad (21)$$

$$F_{sp} = 1 + \left(\frac{0.34\,\alpha R}{\lambda_{tr}} \right) \qquad R \ll \lambda_{tr} \qquad (22)$$

where $$\alpha = 1 - e^{-\mu d} (1 - \mu d) + \mu^2 d^2 E_1 (-\mu d) \qquad (23)$$

$$L^2 = \lambda_{tr} \lambda_a / 3 \left(1 - \frac{2\lambda_{tr}}{5\lambda_a} \right)^2 \qquad (24)$$

R is the foil radius; λ_{tr} and λ_a are the transport and absorption mean free paths; μ is the macroscopic absorption coefficient of the foil corresponding to the effective thermal neutron energy (Average energy of the Maxwellian distribution of neutrons) of 0.032 ev at 20°c; d is the linear thickness of the foil; $E_1 (-\mu d)$ is the exponential integral function tabulated for example in the table of Higher Functions.[22]

The correction factor for flux depression for the Indium foils used in the experiment is obtained as 1.028906. The activities A (r), A (r) r^2, A (r) r^4 etc. corrected for this effect are shown in table 9. The data used here are those

for cadmium covered In foils. But this will not affect the age value as all the activities are multiplied by the same factor.

3. Absorption of 1.46 ev neutrons by cadmium covers

A fraction of the 1.46 ev neutron flux is absorbed by the cd cover as it has a finite cross section at 1.46 ev, though it is smaller compared to its thermal absorption cross section. A correction factor has to be applied to get the correct values of the In foil activity from the observed values. This factor F_{cd}, which when multiplied by the observed activity gives the activity which would have been obtained if there were no absorption of 1.46 ev neutron flux by the cd cover. Tittle[23] has given Bothe's expression for α, the average probability of absorption of a neutron by a layer of thickness d, as already given by equation 23.

If the neutron flux (1.46 ev) at the surface of the cd cover is S, the flux at a depth 'd' of the cd cover will be $(1 - \alpha)$ S. The flux that is experimentally measured by the activity of cd covered In foil is thus equal to $(1 - \alpha)$ S. If there were no absorption of In resonance neutrons by the cd cover, the flux at the position of In foil would have been equal to S. To get the flux S, the experimentally measured flux is to be divided by $(1 - \alpha)$.

$$\therefore F_{cd} = 1 / (1 - \alpha) \tag{25}$$

Here the absorption cross section of cd corresponds to 1.46 ev. The calculated value of F_{cd} for the covers used in the experiment is 1.025388. This correction will not affect the final age value as all the activities are multiplied by the same factor. However, the activities A (r), A (r) r^2, A (r) r^4 etc. corrected for this effect are shown in Table 10.

4. Correction for finite size of source

The finite sized source used in an experiment is an approximation to the theoretical point source. Therefore a correction factor has to be used on the measured activities to account for the finiteness of the source. The correction term for finite size of the source is given in the Reactor Handbook.[24] The correction is expressed as;

$$A(r_o) = A_m(r_o) - \left(\frac{(b_1^{\,2} + b_2^{\,2} + 24\, a_2^{\,2})}{24\, r_o} \frac{d A_m}{dr} \right)_{r_o} \qquad (26)$$

where b_1 and b_2 are the length and diameter of the source. This expression however, strictly speaking, applied to rectangular sources and plane circular detectors.

Here $A_m(r_o)$ = observed activity of the foil at a distance r_o from the source (properly corrected for flux depression and cd absorption of In resonance neutrons)

$A(r_o)$ = Activity that would be given by a point source

a_2 = radius of the detecting foil

$\left.\frac{d A_m}{dr}\right|_{r_o}$ = Derivative of the experimental curve A_m vs r, at a distance r_o.

Both the front and back activities are corrected for the above effect. The activities A (r), A (r) r^2, A (r) r^4 etc. after correcting for finite source size are shown in table 11.

5. Correction for high energy activation of the foil

Since In has a finite cross section for energies greater than 1.46 ev there will be some contribution to the activity of the foil due to the absorption by it of high energy neutrons. The method used here to correct the error in the measured activities due to this effect is that given by Wade.[26]

At distances less than $\sqrt{\tau}$ ($\sqrt{\tau}$ is the slowing down length) from the source, the activity of a cd covered In foil is due to the absorption of both the 1.46 ev neutrons and the high energy neutrons. Covering the foils with cd and In, will have little effect on the activity due to high energy neutrons, but the resonance activity will be decreased to a great extent. Hence at distances less than $\sqrt{\tau}$, the activities of cd covered In foil and cd covered In covered In foil are given by

$$A_1 \text{ (cd)} = A \text{ (1.46)} + A \text{ (High Energy)} \tag{27}$$

$$A_1 \text{ (cd + In)} = g_e A \text{ (1.46)} + A \text{ (High Energy)} \tag{28}$$

g_o is the self shielding factor for the In foils used in the experiment. At large distances i.e. greater than $\sqrt{\tau}$, the contribution of high energy neutrons is negligible. Hence at distances greater than $\sqrt{\tau}$, the activities of cd covered In and of cd covered In covered In foils are given by

$$A_2 \text{ (cd)} = A' \text{ (1.46)} \qquad (29)$$

$$A_2 \text{ (cd + In)} = g_o A' \text{ (1.46)} \qquad (30)$$

The activities of cd covered In covered In foils were determined at the same distances from the source, at which cd covered In foil activities were determined. But the activities of cd covered In covered In foil activities could be determined only upto a distance of 22.5 cms from the source. Beyond this distance the activities were very small to be detected by the G.M. counting set up. Equations (29) and (30) were used for only the point at 22.5 cms to calculate g_o. Using this value of g_o the other activities, A (1.46) at distances less than 22.5 cms were determined using equations (27) and (28). The values of activity after subtracting the high energy contributions are shown in table 14.

6. Correction for finite foil size

An empirical correction factor is applied to correct for the finite size of the foil. Doerner et al[2] have determined the effect of foil thickness on the 2nd moment of the flux.

The 2nd moment of the flux were determined using foils of different thicknesses. They found a linear relation between the foil thickness and the 2nd moment of flux. A least square fit was used for the measured data of 2nd moment of flux and foil thickness. The relation found by them is given as

$$\overline{r_o^2} = \overline{r^2}_{\text{measured}} + 0.00304\ d \qquad (31)$$

where d = foil thickness in mg/cm^2

$\overline{r_o^2}$ = the 2nd moment that might have been determined with infinitely thin foil.

$\overline{r^2}_{\text{measured}}$ = Measured 2nd moment of flux

This correction for the In foils used in the experiment is calculated as + 0.003088 cm^2, for the age value.

7. Correction for density change

The age values have to be specified for pure water with a density of 1.0 gm/cc. Other things remaining invariant, the age value varies inversely with the density of the moderating medium. An average water temperature of 19°c was noted during the period of the experiment and the density of water at this temperature is 0.99843 gm/cc.

$\therefore$ Age at 1 gm/cc = ρ^2 x Age at a measured density ρ .

$\therefore$ Correction to be applied on the age value = $(\rho^2 - 1)$ x Measured age value at a density ρ .

= $(0.99843^2 - 1)$ x Age value

CHAPTER V

RESULTS & DISCUSSION

5.1 Calculations and Results

Using the average activities of front and back sides of the foil, the 2nd moment and the 4th moment of activities i.e $A(r)\, r^2$ and $A(r)\, r^4$ respectively are calculated and these are integrated with respect to distance from zero to infinity. The variation of $A(r)\, r^2$ and $A(r)\, r^4$ with distance are shown in figures 14 and 15 on semilog graphs. The point at which the curve of $\ln(A(r)\, r^2)$ versus r becomes linear is noted to be at 29.9 cms. Integration from zero to 29.9 cms is carried out numerically by using 16 point Gauss quadrature technique. The Gauss quadrature abscissae and weights used in this calculation are those reported by Davis and Rabinowitz.[25] The Gauss quadrature formula requires the values of $A(r)\, r^2$ and $A(r)\, r^4$ at certain points decided by the tabulated abscissae values for the 16 point formula. The values of $A(r)\, r^2$ and $A(r)\, r^4$ at these points are obtained using the experimentally determined values of $A(r)\, r^2$ and $A(r)\, r^4$, by Lagragian interpolation. The interpolation was however done using only 3 points i.e. (2nd degree curve) near the point at which interpolation was done.

The integration from 29.9 cms to infinity is carried out by using the fact that at large distances from the source the slowing down density or the flux can be assumed to have an

FIGURE 14: EXPERIMENTAL CURVE OF $A(x)x^2$ VERSUS x

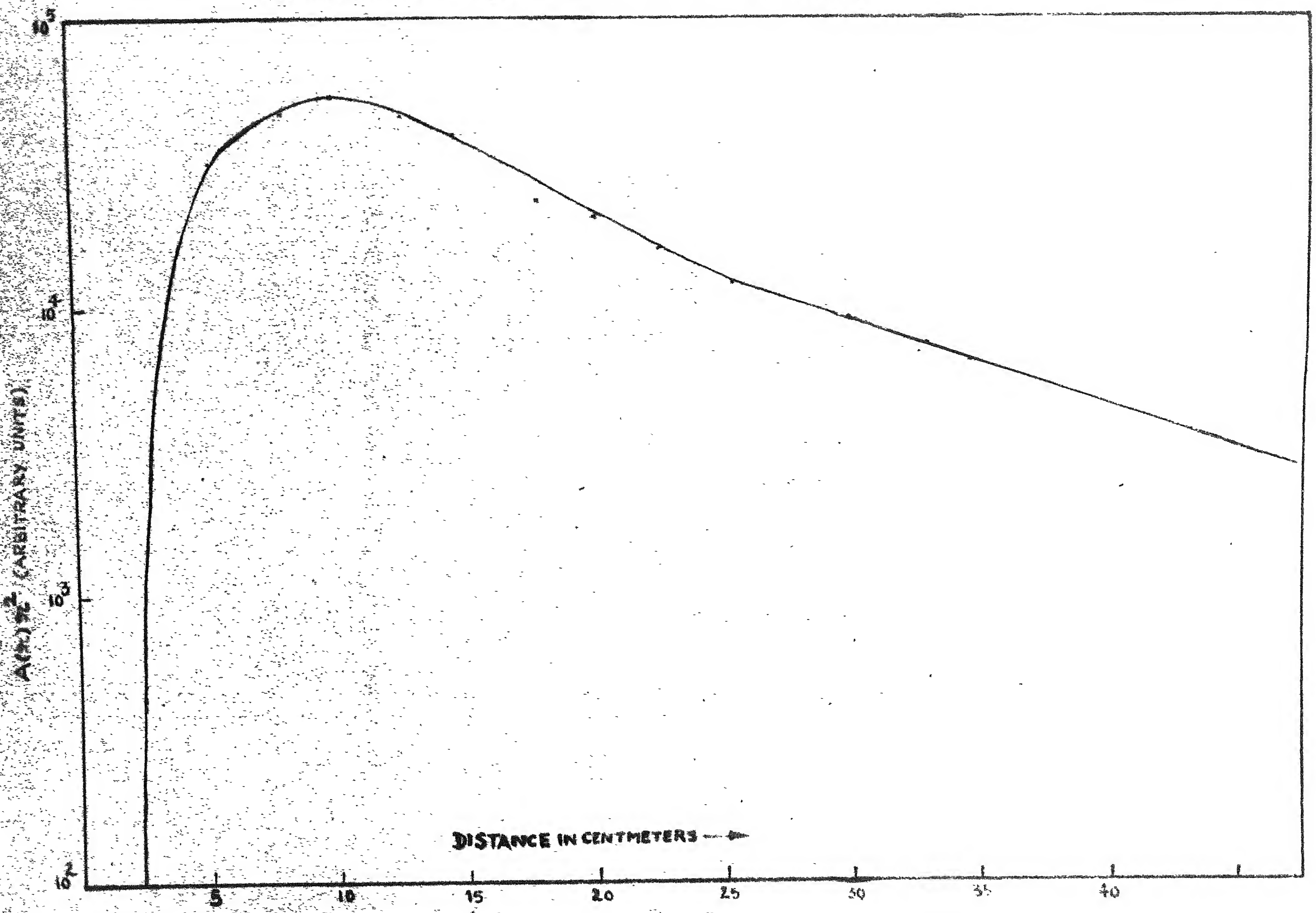
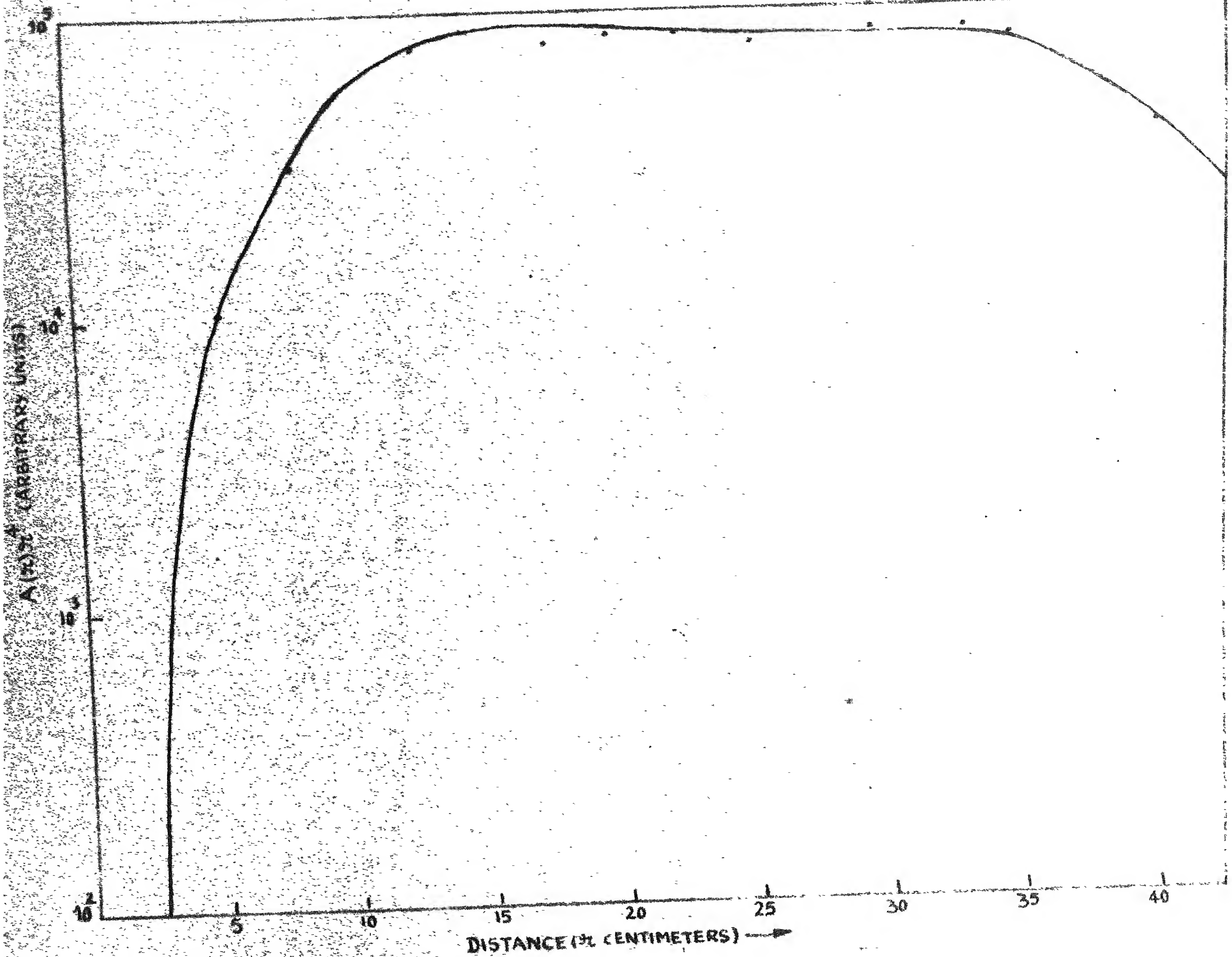


FIGURE 15: EXPERIMENTAL CURVE OF $A(x)x^4$ VERSUS x.



asymptotic distribution given by

$$\phi(r) \propto \frac{e^{br}}{r^2} \quad (\text{ b will be negative})$$

Also, $A(r) \propto \frac{e^{br}}{r^2}$

$$\text{i.e} \quad A(r)\, r^2 = a\, e^{br} \tag{32}$$

Hence the plot of $\ln (A(r)\, r^2)$ versus r is a straight line. A least square straight line fit was made for the values of $\ln (A(r)\, r^2)$ at the remaining data points for $r \geqq 29.9$ cms. The values of 'b' and 'a' were calculated using the least square fit criteria. The integration from 29.9 cms to infinity was then analytically evaluated for both $A(r)\, r^2$ and $A(r)\, r^4$. The distance at which the curve $\ln(A(r)\, r^2)$ versus r becomes linear will be denoted by r_m (= 29.9 cms)

$$\int_{r_m}^{\infty} A(r)\, r^2\, dr = \int_{r_m}^{\infty} a\, e^{br}\, dr = a \frac{e^{br}}{b} \Big|_{r_m}^{\infty} = -\frac{a}{b}\, e^{br_m} \tag{33}$$

$$\int_{r_m}^{\infty} A(r)\, r^4\, dr = \int_{r_m}^{\infty} a\, e^{br}\, r^2\, dr = -\frac{a}{b^3}\, e^{br_m}(r_m^2\, b^2 - 2br_m + 2) \tag{34}$$

The integral $\int_0^{r_m} A(r)\, r^2\, dr$ which was numerically evaluated, was added to (33) to get $\int_0^{\infty} A(r)\, r^2\, dr$. Similarly $\int_0^{r_m} A(r)\, r^4\, dr$ was added to (34) to get $\int_0^{\infty} A(r)\, r^4\, dr$. The age value was calculated using equation (13). The final

age values are calculated for 3 different cases in which the activities were obtained using

(1) bare In foils

(2) cd covered In foils

(3) using (2) and also the activities of cd covered In covered In foils.

Table 12 shows the final results obtained using bare Indium foil. Table 13 shows the results obtained when the activities of the foil are not corrected for high energy neutron contribution. Table 14 shows the final results when the activities of the cd covered In foil are corrected for high energy neutron activations. Thus the final value of age of Pu - Be neutron source to the In resonance with all errors and corrections is shown in table 14.

5.2 Error Analysis

The inherent limitations of the experiment are the finite size of the medium, finite size of the source and foils which represent the theoretical infinite medium, point source and point detector foils. The two factors which give rise to errors in the age measurement are obviously, the error in the distances measured and the errors in the activities measured. The effect of these two errors on the measured age value have been estimated. The maximum error in the distance measurements is estimated to be ± 0.1 cm because the distances were measured

with a meter scale. The error in the activities is of statistical nature. As is well known, the error in the observed number of counts N is $\pm\sqrt{N}$.

Most of the physical measurements confirm approximately to a normal distribution about a mean value of $\bar{r}$. A physical quantity subjected to a series of measurements assumes the character of a discontinuous variable as a result of statistical fluctuations. Hence the errors in distance measurement and activity measurement are of statistical nature. The following basic rules for error estimation have been used.[27] If two ~~this~~ quantities R_1 and R_2 are erroneous by $\pm r_1$ and $\pm r_2$ respectively, then

$$\text{Error in } (R_1 + R_2) \text{ or } (R_1 - R_2) \text{ is } \pm\sqrt{r_1^2 + r_2^2} \qquad (35)$$

$$\text{Error in } R_1 \; R_2 \text{ is } \pm R_1 R_2 \sqrt{\left(\frac{r_1}{R_1}\right)^2 + \left(\frac{r_2}{R_2}\right)^2} \qquad (36)$$

$$\text{Error in } R_1 / R_2 \text{ is } \pm \frac{R_1}{R_2} \sqrt{\left(\frac{r_1}{R_1}\right)^2 + \left(\frac{r_2}{R_2}\right)^2} \qquad (37)$$

$$\text{Now Age} = \frac{1}{6} \frac{\int_0^\infty A(r)\, r^4\, dr}{\int_0^\infty A(r)\, r^2\, dr} = \frac{R_1}{R_2}$$

Using equation (37), the error in age can be written as

$$\text{Error in age} = \pm \text{ age} \times \sqrt{\left[\left(\frac{\text{error in } \int_0^\infty A(r)\, r^2\, dr}{\int_0^\infty A(r)\, r^2\, dr}\right)^2 + \left(\frac{\text{error in } \int_0^\infty A(r)\, r^4\, dr}{\int_0^\infty A(r)\, r^4\, dr}\right)^2\right]}$$

The integral $\int_0^\infty A(r)\, r^2\, dr$ can be taken as a sum $\sum_{i=1}^{N-1} \left(\left(A(r_i)\, r_i^2 + A(r_{i+1})\, r_{i+1}^2 \right)(r_{i+1} - r_i)/2 \right)$, using the trapezoidal rule for integration. N is the number of points at which activities were measured. If the error in each term of the above summation is known, the error in the integral can be calculated using equation (35). Denoting $(A(r_i)\, r_i^2 + A(r_{i+1})\, r_{i+1}^2)$ by A and $(r_{i+1} - r_i)$ by B, the error in the ith term of the above summation using equation (36) is given by

$$\frac{(A(r_i)\, r_i^2 + A(r_{i+1})\, r_{i+1}^2)\,(r_{i+1} - r_i)}{2} \sqrt{\left(\frac{\text{error in A}}{A}\right)^2 + \left(\frac{\text{error in B}}{B}\right)^2}$$

Knowing the errors in r_i ($\pm$ 0.1 cm) and $A(r_i)$, the errors in A and B can easily be calculated using equations (35) and (36). By similar calculations the error in the integral $\int_0^\infty A(r)\, r^4\, dr$ can also be calculated. Hence the error in the age value is calculated. The final errors in the age value are shown in tables 12, 13 and 14 for the 3 different cases mentioned in (3.2).

5.3 Discussion

Front and back activities of foil:

Because of the finite size of the foil, the activity acquired by a foil has angular dependance as the neutron flux i.e., the activity of the foil is not exactly proportional to the flux at the centre of the foil. This was observed by

measuring the activities of the front side and back side of the foil and they were found to be different. The ratios of the front to back activities are tabulated in tables 8, 9 and 10. It has been shown by Lombard and Blanchard[6] that the average of front and back activities of a foil is not proportional to the flux at the centre of the foil. But it was shown by them that the average of front and back activities is proportional to the flux if the second and higher Legendre components of the flux are negligible. This effect was also investigated by Doermer et. al[2] by measuring the ratio of front to back activities of foils of different thicknesses. They found that foil thickness upto about 40 mg/cm^2 are essentially flux detectors and over about 120 mg/cm^2 are current detectors. The foils used in the present experiment were of 184.912 mg/cm^2 thickness and hence were current detectors.

Discussion of the age values

In the present work large In foils, cd covered In foils and cd covered In covered In foils were utilised to find the effects of thermal neutron activity and high energy (high energy means energies greater than In resonance energy) activity on the age value. The value of age using all the necessary corrections is 53.7 ± 4.04 cm^2. The age value obtained by Valente and Sullivan[1] is 52.8 ± 2.5 cm^2. They neglected the high energy contribution of the activity as well as the effect of stainless steel wire and Aluminum rod which were used to suspend the source and foil holders in their experiment.

The value of age calculated using the activities of bare In foils is 57.03 $\pm$ 2.2 cm^2. This value is greater than the age to In resonance as calculated above viz 53.7 cm^2. This is because the activities are caused not only by In resonance neutrons but also by the thermal neutrons. Here the high energy contribution is negligible because the cross section of In at high energies is much smaller than the cross section at thermal energies. Also, due to diffusion at thermal energies, the neutrons might be detected at far greater distance, from the point where they just thermalized. The value of age to thermal energy is greater than the age to In resonance. Hence the age value with the bare In foil data is greater than the age to In resonance.

The age value determined using the data of cd covered In foil is 50.4 $\pm$ 3.5 cm^2. This value is the value obtained when the high energy contribution of the activity is neglected. Hence this value is some sort of average of the ages to In resonance and age to higher energies. Since the age to higher energies is smaller than the age to In resonance, the age determined with the activities uncorrected for high energy contribution will be smaller than the value of age to In resonance.

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TABLE 5

DATA OF BARE INDIUM FOIL

DISTANCE	IRRADIATION TIME	WAITING TIME BEFORE COUNT 1ST SIDE	WAITING TIME BEFORE COUNT 2ND SIDE	COUNTING TIME	NUMBER OF COUNTS 1ST SIDE	NUMBER OF COUNTS 2ND SIDE	[illegible]
5.45	530.00	5.0	16.0	1[illegible]	94431.0	82331.	[illegible]
1[illegible]	552.00	5.0	16.0	1[illegible]	61672.0	53353.	[illegible]
14.60	574.00	5.0	16.0	1[illegible]	27635.0	25027.	[illegible]
2[illegible]	596.00	5.0	16.0	1[illegible]	8942.0	7855.	[illegible]
2[illegible].35	618.00	5.0	16.0	1[illegible]	3365.0	3364.	[illegible]
2[illegible].90	640.00	5.0	16.0	1[illegible]	[illegible]	1291.	[illegible]
34.50	662.00	5.0	16.0	1[illegible]	[illegible]	680.	[illegible]
4[illegible]	750.00	5.0	16.0	1[illegible]	[illegible]	329.	[illegible]
45.35	772.00	5.0	16.0	1[illegible]	[illegible]	247.	[illegible]
51.72	794.00	5.0	16.0	1[illegible]	[illegible]	165.	[illegible]
55.4[illegible]	816.00	5.0	16.0	1[illegible]	[illegible]	114.	[illegible]

TABLE 6

DATA OF CADMIUM COVERED INDIUM FOIL

DISTANCE	IRRADIATION TIME	WAITING TIME BEFORE COUNT 1ST SIDE	WAITING TIME BEFORE COUNT 2ND SIDE	COUNTING TIME	NUMBER OF COUNTS 1ST SIDE	NUMBER OF COUNTS 2ND SIDE	[illegible] COUNTS
5.45	510.[illegible]	10.0	21.0	13.0	[illegible]531.0	9511.[illegible]	[illegible]
[illegible].15	7[illegible]	12.0	25.0	1[illegible]	7266.[illegible]	5[illegible]47.[illegible]	[illegible]
1[illegible].00	533.[illegible]	10.0	26.0	15.0	721[illegible].0	4955.[illegible]	[illegible]
12.75	450.[illegible]	10.0	26.0	15.[illegible]	3952.0	260[illegible]	[illegible]
14.60	585.[illegible]	10.0	31.0	2[illegible]	296[illegible].0	2548.[illegible]	[illegible]
17.80	475.[illegible]	10.0	26.0	15.	1295.0	872.0	[illegible]
20.00	635.[illegible]	1[illegible]	31.0	20.0	983.0	9[illegible].6	[illegible]
22.50	534.[illegible]	10.0	31.0	2[illegible]	675.[illegible]	638.[illegible]	[illegible]
25.35	68[illegible]	10.0	31.[illegible]	2[illegible]	516.0	384.[illegible]	[illegible]
29.90	1555.[illegible]	10.0	26.0	15.	[illegible]	[illegible]	[illegible]
32.75	449.[illegible]	10.[illegible]	31.0	2[illegible]	294.0	264.[illegible]	[illegible]
34.50	1587.[illegible]	10.[illegible]	31.[illegible]	[illegible]	289.0	255.[illegible]	[illegible]
40.00	162[illegible]	10.0	31.0	2[illegible]	214.[illegible]	225.[illegible]	[illegible]

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TABLE 7

DATA OF (INDIUM+CADIUM) COVERED INDIUM FOIL

DISTANCE	IRRADIATION TIME	WAITING TIME BEFORE COUNT 1ST SIDE	WAITING TIME BEFORE COUNT 2ND SIDE	COUNTING TIME	NUMBER OF COUNTS 1ST SIDE	NUMBER OF COUNTS 2ND SIDE	BACKGROUND COUNTS
5.45	432.00	10.0	21.0	10.0	4546.0	4046.0	14[illegible].
7.00	415.00	10.0	21.0	10.0	3725.0	3332.0	14[illegible]
8.15	393.00	10.0	21.0	10.0	2716.0	2656.0	14[illegible].
10.00	534.00	10.0	21.0	10.0	1695.0	1574.0	14[illegible].
12.75	450.00	10.0	21.0	10.0	1057.0	91[illegible].0	14[illegible]
14.60	487.00	10.0	21.0	10.0	757.0	601.0	14[illegible]
16.00	432.00	10.0	21.0	10.0	655.0	586.0	14[illegible]
17.80	483.00	10.0	21.0	10.0	419.0	407.0	14[illegible].
20.00	472.00	10.0	21.0	10.0	316.0	297.0	14[illegible]
22.50	536.00	10.0	21.0	10.0	222.0	216.0	14[illegible]

ACTIVITIES ETC. [illegible]

FRONT ACTIVITIES, 2ND MOMENT, 4TH MOMENT ETC. OF INDIUM FOIL ACTIVITY

DISTANCE	SATURATED ACTIVITY	2ND MOMENT OF ACTIVITY	4TH MOMENT OF ACTIVITY	LOG(2ND MOMENT OF ACTIVITY)	RATIO OF FRONT TO BACK ACTIVITY
5.45	1314.0374	39.5[illegible].9568	116 [illegible].14	10.572699	1.113746
[illegible].15	894.5[illegible]35	59161.3912	393 178.84	10.988160	1.257845
1[illegible].00	585.[illegible]7	58556.9672	5897696.64	10.984563	1.197921
12.75	317.7869	5166[illegible].2376	339[illegible]17.36	10.852444	1.263778
14.6[illegible]	199.9448	4262 .2228	9[illegible]84926.72	10.660[illegible]84	1.122130
17.[illegible]	93.9373	30398.7848	963 917.20	10.322092	1.291496
2[illegible].00	59.8436	2393[illegible].858[illegible]	957[illegible]943.44	10.083300	1.185569
2[illegible].50	33.2[illegible]3	16807.6268	850[illegible]860.96	9.729588	1.196648
2[illegible].35	2[illegible].37[illegible]7	1359[illegible].6412	841[illegible]340.46	9.479653	1.311677
29.9[illegible]	12.99[illegible]7	1162 .9239	1038[illegible]222.08	9.360563	1.814895
32.75	7.4526	7[illegible]9[illegible].3820	857[illegible]4[illegible]1.68	8.986369	1.225737
34.50	5.7304	6827.7194	812[illegible]692.88	8.828746	1.2359[illegible]5
4[illegible].0[illegible]	[illegible].1[illegible]97	3375.5911	54[illegible] 945.68	8.124326	2.338053

BACK ACTIVITIES, 2ND MOMENT, 4TH MOMENT ETC. OF INDIUM FOIL ACTIVITY

DISTANCE	SATURATED ACTIVITY	2ND MOMENT OF ACTIVITY	4TH MOMENT OF ACTIVITY	LOG(2ND MOMENT OF ACTIVITY)	RATIO OF FRONT TO BACK ACTIVITY
5.45	11[illegible].5539	3556[illegible].4[illegible]16	1041530.08	10.464970	1.113746
9.15	708.1984	4754[illegible].3556	3124534.64	10.758760	1.257845
1[illegible].[illegible]	492.16[illegible]	4921[illegible].[illegible]916	4[illegible]21639.12	10.803976	1.197921
12.75	251.4578	40877.6112	664[illegible]166.56	1[illegible].618338	1.263778
14.6[illegible]	178.1832	3798[illegible].[illegible]368	809[illegible]144.32	10.544855	1.122130
17.8[illegible]	74.2[illegible]39	2353[illegible].[illegible]998	7457177.68	1[illegible].066291	1.291496
2[illegible].[illegible]	5[illegible].481[illegible]	2219[illegible].7160	8[illegible]77086.32	9.913077	1.185569
22.50	27.7444	14[illegible]4[illegible].5884	711 579.[illegible]4	9.550064	1.196648
2[illegible].35	15.53[illegible]2	998 .0802	641[illegible]424.[illegible]	9.208346	1.311677
29.9[illegible]	[illegible].1622	64[illegible].0847	572[illegible]421.68	8.764535	1.814895
3[illegible].75	6.[illegible]8[illegible]1	6521.2380	699[illegible]488.8[illegible]	8.782827	1.225737
34.5[illegible]	[illegible].6614	5524.4713	557[illegible]501.84	8.616943	1.2359[illegible]5
4[illegible].[illegible]	[illegible].9024	1443.7616	231[illegible]018.56	7.275007	2.338053

TABLE 8

ACTIVITIES ETC. WITHOUT ANY CORRECTION

FRONT ACTIVITIES, 2ND MOMENT, 4TH MOMENT ETC. OF INDIUM FOIL ACTIVITY

DISTANCE	SATURATED ACTIVITY	2ND MOMENT OF ACTIVITY	4TH MOMENT OF ACTIVITY	LOG(2ND MOMENT OF ACTIVITY)	RATIO OF FRONT TO BACK ACTIVITY
5.45	1314.8374	39[illegible].9568	116[illegible].14	10.572699	1.113746
[illegible].15	89[illegible].6[illegible]35	5916[illegible].3912	393[illegible]178.84	10.938160	1.257845
10.00	58[illegible].5577	5895[illegible].9672	589[illegible]696.64	10.984563	1.197921
12.75	317.7869	5166[illegible].2376	839[illegible]17.36	10.852444	1.263778
14.6[illegible]	14[illegible].944[illegible]	4262[illegible].2228	9084926.72	10.660[illegible]84	1.122130
17.8[illegible]	9[illegible].[illegible]373	3039[illegible].7848	963[illegible]917.20	10.322092	1.291496
20.00	59.3496	2393[illegible].8586	957[illegible]943.44	10.[illegible]8330[illegible]	1.185569
22.50	33.2333	16807.6268	850[illegible]860.96	9.729588	1.196648
25.35	2[illegible].[illegible]7[illegible]7	13[illegible]9[illegible].6412	841[illegible]340.48	9.479653	1.311677
29.9[illegible]	12.9987	1162[illegible].9239	1038[illegible]222.08	9.360563	1.814895
32.75	7.4526	799[illegible].3820	857[illegible]4[illegible]1.68	8.986369	1.225737
34.50	[illegible].7364	6827.7194	812[illegible]692.88	8.828746	1.235905
4[illegible].00	2.1[illegible]97	337[illegible].5911	540 945.68	8.124326	2.338053

BACK ACTIVITIES, 2ND MOMENT, 4TH MOMENT ETC. OF INDIUM FOIL ACTIVITY

DISTANCE	SATURATED ACTIVITY	2ND MOMENT OF ACTIVITY	4TH MOMENT OF ACTIVITY	LOG(2ND MOMENT OF ACTIVITY)	RATIO OF FRONT TO BACK ACTIVITY
[illegible].45	11[illegible].5539	3506[illegible].4[illegible]16	1041530.08	10.464970	1.113746
[illegible].15	7[illegible].1984	47[illegible]4[illegible].3056	3124534.64	10.758760	1.257845
10.00	49[illegible].16[illegible]9	4921[illegible].[illegible]916	4721609.12	10.[illegible]3976	1.197921
12.75	2[illegible]1.4578	40877.6112	664[illegible]166.56	1[illegible].618338	1.263778
14.60	17[illegible].1832	3798[illegible].[illegible]368	809[illegible]144.32	10.544[illegible]5	1.122130
17.80	74.2839	2353[illegible].0998	7457177.68	1[illegible].[illegible]66[illegible]91	1.291496
2[illegible].[illegible]0	5[illegible].4818	2019[illegible].7160	8[illegible]77086.32	9.913[illegible]77	1.185569
22.50	27.7444	14[illegible]45.5884	711 579.[illegible]4	9.[illegible]64	1.196648
25.35	15.5382	998 .0802	641[illegible]424.[illegible]	9.208346	1.311677
29.90	7.1622	64[illegible].0847	5724421.68	8.764535	1.814895
32.75	6.[illegible]8[illegible]1	6521.2880	699[illegible]488.8[illegible]	8.782827	1.225737
34.50	4.6414	552[illegible].4713	657[illegible]501.84	8.616943	1.235905
4[illegible].[illegible]	[illegible].9974	1443.7616	231[illegible]018.56	7.275[illegible]07	2.338053

ACTIVITIES CORRECTED FOR FLUX DEPRESSION

FLUX DEPRESSION CORRECTION FACTOR= 1.02[illegible]9[illegible]6

FRONT ACTIVITIES,2ND MOMENT,4TH MOMENT ETC. OF INDIUM FOIL ACTIVITY

DISTANCE	SATURATED ACTIVITY	2ND MOMENT OF ACTIVITY	4TH MOMENT OF ACTIVITY	LOG(2ND MOMENT OF ACTIVITY)	RATIO OF FRONT TO BACK ACTIVITY
5.45	1357.1965	41203.9252	1223832.84	10.626267	1.113746
8.15	935.8228	62423.3763	4140449.52	11.041727	1.257845
10.00	622.0126	62201.2616	622 126.98	11.038131	1.197921
12.75	335.2742	54504.0064	886 144.96	10.906011	1.263778
14.60	210.9473	44964.5364	9584853.66	10.713652	1.122130
17.80	101.2146	32065.4648	1016 888.96	10.375660	1.291496
20.00	63.1431	25257.2258	10102890.24	10.136868	1.185569
22.50	35.0272	1773 .5196	8977088.00	9.783156	1.196648
25.35	21.4916	1381 .9956	8875256.32	9.533220	1.311677
27.90	13.7139	12260.4022	1096 922.24	9.414130	1.814895
32.75	7.8627	8433.2424	9045180.48	9.039937	1.225737
34.50	6.0520	7262.4364	8573890.08	8.882313	1.235905
40.00	2.2258	3561.3437	569 149.76	8.177893	2.338053

BACK ACTIVITIES,2ND MOMENT,4TH MOMENT ETC. OF INDIUM FOIL ACTIVITY

DISTANCE	SATURATED ACTIVITY	2ND MOMENT OF ACTIVITY	4TH MOMENT OF ACTIVITY	LOG(2ND MOMENT OF ACTIVITY)	RATIO OF FRONT TO BACK ACTIVITY
5.45	1245.5176	36994.9872	1091843.59	10.518538	1.113746
8.15	747.1692	49624.0480	3294472.12	10.812328	1.257845
10.00	519.2436	51924.3636	5192436.28	10.857543	1.197921
12.75	265.2931	43127.0312	7010838.00	10.671905	1.263778
14.60	137.9883	40071.5920	8541660.48	10.598423	1.122130
17.80	78.3716	24831.2482	7867532.56	10.119858	1.291496
20.00	53.2597	21301.8844	8521553.68	9.966645	1.185569
22.50	29.2711	14821.4916	7591861.36	9.653631	1.196648
25.35	16.3845	10529.2658	6760342.96	9.261914	1.311677
27.90	7.5563	6757.4348	6739426.24	8.818103	1.814895
32.75	6.4147	688 .1425	7379382.80	8.836395	1.225737
34.50	4.8968	5821.4729	6937339.76	8.670510	1.235905
40.00	.9520	1523.2792	2437134.68	7.328575	2.338053

ACTIVITIES CORRECTED FOR CADIUM ABSORPTION

CADIUM CORRECTION FACTOR= 1.02538-

FRONT ACTIVITIES,2ND MOMENT,4TH MOMENT ETC. OF INDIUM FOIL ACTIVITY

DISTANCE	SATURATED ACTIVITY	2ND MOMENT OF ACTIVITY	4TH MOMENT OF ACTIVITY	LOG(2ND MOMENT OF ACTIVITY)	RATIO OF FRONT TO BACK ACTIVITY
5.45	134[illegible].2188	4504[illegible].4672	1189450.46	10.597771	1.113746
[illegible].15	91[illegible].4194	6067[illegible].5960	402[illegible]959.04	11.013231	1.257845
1[illegible].[illegible]	[illegible]4.5378	69453.7792	6049377.84	11.009634	1.197921
12.75	325.3558	52971.7981	8611227.84	10.877515	1.263778
14.60	2[illegible]5.[illegible]21[illegible]	4370[illegible].2744	931[illegible]576.72	10.685155	1.122130
17.85	9[illegible].3739	31165.5048	987[illegible]428.80	10.347163	1.291496
2[illegible].[illegible]	61.3691	24547.6490	981[illegible]059.44	10.108371	1.185569
23.50	34.[illegible]431	17234.3422	872[illegible]885.60	9.754659	1.196648
25.35	2[illegible].8878	1342[illegible].9692	862[illegible]914.72	9.504724	1.311677
24.90	1[illegible].3287	1191[illegible].9583	10652986.00	9.385634	1.814895
32.75	7.5418	819[illegible].3197	8791064.96	9.011441	1.225737
34.50	5.9826	7001.0629	833[illegible]015.04	8.853817	1.235905
4[illegible].[illegible]	2.1633	3461.2912	553[illegible]065.52	8.149397	2.338053

BACK ACTIVITIES,2ND MOMENT,4TH MOMENT ETC. OF INDIUM FOIL ACTIVITY

DISTANCE	SATURATED ACTIVITY	2ND MOMENT OF ACTIVITY	4TH MOMENT OF ACTIVITY	LOG(2ND MOMENT OF ACTIVITY)	RATIO OF FRONT TO BACK ACTIVITY
5.45	1210.5260	3595[illegible].6492	1067972.65	10.490041	1.113746
[illegible].15	726.1733	48234.5744	320[illegible]861.00	10.783831	1.257845
1[illegible].[illegible]	[illegible]04.6560	50465.6504	594[illegible]560.00	10.829047	1.197921
12.75	2[illegible]7.8419	4191[illegible].4204	681[illegible]875.44	10.643459	1.263778
14.60	182.7070	3894[illegible].8200	830[illegible]691.04	10.569927	1.122130
17.85	76.1698	2413[illegible].6388	764[illegible]562.00	1[illegible].091362	1.291496
2[illegible].[illegible]	51.7034	2070[illegible].3728	828[illegible]149.04	9.938148	1.185569
22.50	[illegible].44[illegible]	1440[illegible].1896	7291103.92	9.575135	1.196648
25.35	1[illegible].9245	1023[illegible].4565	657[illegible]249.28	9.233418	1.311677
29.90	7.3443	656[illegible].6475	586[illegible]754.56	8.789606	1.814895
32.75	6.2345	608[illegible].8517	7172066.32	8.807898	1.225737
34.50	4.7593	566[illegible].7277	674[illegible]442.00	8.642514	1.235905
4[illegible].[illegible]	0.9253	148[illegible].4161	236[illegible]665.78	7.300079	2.338053

ACTIVITIES CORRECTED FOR FINITE SIZE OF SOURCE

FRONT ACTIVITIES, 2ND MOMENT, 4TH MOMENT ETC. OF INDIUM FOIL ACTIVITY

DISTANCE	SATURATED ACTIVITY	2ND MOMENT OF ACTIVITY	4TH MOMENT OF ACTIVITY	LOG(2ND MOMENT OF ACTIVITY)	RATIO OF FRONT TO BACK ACTIVITY
5.45	1500.512	44563.9684	0.1323810E 07	10.704793	1.071768
8.15	1013.936	6768[illegible].5920	0.4495713E 07	11.122599	1.248082
10.00	688.420	68842.0112	0.6884201E 07	11.139570	1.236646
12.75	359.815	58492.3880	0.9508669E 07	10.976652	1.267573
14.60	224.597	47875.1096	0.1020506E 08	10.776351	1.160181
17.80	166.403	33712.6896	0.1068153E 08	10.425630	1.284945
20.00	65.122	26048.8068	0.1041952E 08	10.167727	1.213570
22.50	36.418	18436.4714	0.9333463E 07	9.822086	1.194234
25.35	21.685	13935.4448	0.89[illegible]230E 07	9.542191	1.301777
29.90	13.959	12479.2432	0.1115657E 08	9.431822	1.816843
32.75	8.117	8705.9820	0.9337710E 07	9.071766	1.269810
34.50	6.157	7329.7037	0.8722990E 07	8.899554	1.234259
40.00	2.266	3626.1828	0.58[illegible]5[illegible]92E 07	8.196487	2.246302

BACK ACTIVITIES, 2ND MOMENT, 4TH MOMENT ETC. OF INDIUM FOIL ACTIVITY

DISTANCE	SATURATED ACTIVITY	2ND MOMENT OF ACTIVITY	4TH MOMENT OF ACTIVITY	LOG(2ND MOMENT OF ACTIVITY)	RATIO OF FRONT TO BACK ACTIVITY
5.45	14[illegible].935	41584.5332	0.1235165E 07	10.635484	1.071768
8.15	816.442	54231.0848	0.3632798E 07	10.900991	1.248082
10.00	556.683	55666.3280	0.5566833E 07	10.927167	1.236646
12.75	283.861	46145.1912	0.7501478E 07	10.739548	1.267573
14.60	193.588	41265.2229	0.8796195E 07	10.627775	1.160181
17.80	82.807	26230.6726	0.8312827E 07	10.174913	1.284945
20.00	53.662	21464.6162	0.8585846E 07	9.974161	1.213570
22.50	30.495	15437.9112	0.7815443E 07	9.644582	1.194234
25.35	16.658	10704.9370	0.6879233E 07	9.278460	1.301777
29.90	7.683	6868.6428	0.6140635E 07	8.834722	1.816843
32.75	6.392	6856.1271	0.7353625E 07	8.832898	1.269810
34.50	4.989	5937.7357	0.7067390E 07	8.689083	1.234259
40.00	1.0[illegible]9	1615.1805	0.2584289E 07	7.387202	2.246302

TABLE 13

AVERAGE OF FRONT AND BACK ACTIVITIES,2ND MOMENT,4TH MOMENT ETC.

DISTANCE	SATURATED ACTIVITY	2ND MOMENT OF ACTIVITY	4TH MOMENT OF ACTIVITY	LOG(2ND MOMENT OF ACTIVITY)
5.45	1450.2736	43078.7573	127487.2	[illegible]
[illegible].15	917.7137	60950.6374	4.40905.6	11.17921
10.00	622.5617	6225[illegible].1696	6225516.9	11.38097
12.75	321.838[illegible]	5231[illegible].7892	85[illegible]373.1	1[illegible].65111
14.65	[illegible].925	4457[illegible].1656	[illegible]59576.5	[illegible]
17.80	94.6[illegible]51	29974.0816	9497178.6	[illegible]
20.00	59.3916	23755.7116	95[illegible]684.5	[illegible]
22.55	33.4562	16937.1910	857[illegible]455.[illegible]	[illegible]7267
25.35	19.1717	1232[illegible].1590	7917231.7	[illegible]
29.90	1[illegible].92[illegible]	9675.9431	[illegible]641601.[illegible]	9.[illegible]7719[illegible]
32.75	7.2546	7781.0566	834[illegible]667.4	[illegible].59447
34.50	5.5737	6635.2197	739[illegible]169.7	[illegible]
4[illegible].[illegible]	1.6386	2621.6516	4194690.5	7.[illegible]71571

RESULTS OF THE EXPERIMENT(WITHOUT CORRECTING FOR HIGH ENERGY ACTIVITY OF FOIL
LEAST SQUARE CONSTANT A= [illegible].568907[illegible]E 06
LEAST SQUARE CONSTANT B=- .1326656

MEASURED AGE WITHOUT ANY CORRECTION= 51.751349

CORRECTION FOR FINITE SIZE OF SOURCE= -1.290973
CORRECTION FOR FINITE FOIL SIZE= .0[illegible]3609
CORRECTION FOR DENSITY CHANGE=-0.156322
TOTAL CORRECTION FOR AGE=-1.355604

AGE OF PO-BE NEUTRONS TO INDIUM RESONANCE= 5[illegible].[illegible]95746

ERROR ANALYSIS IN AGE VALUE

ERROR IN AGE VALUE DUE TO COUNTING ERRORS=+- 3.27[illegible]557
ERROR IN AGE VALUE DUE TO POSITION ERRORS=+- [illegible].2[illegible]751[illegible]
TOTAL ERROR IN THE MEASURED AGE=+- 3.[illegible]6372

TABLE 14

AVERAGE OF FRONT AND BACK ACTIVITIES, 2ND MOMENT, 4TH MOMENT ETC.

DISTANCE	SATURATED ACTIVITY	2ND MOMENT OF ACTIVITY	4TH MOMENT OF ACTIVITY	LOG(2ND MOMENT OF ACTIVITY)
5.45	12[illegible]7.5[illegible]	355[illegible].76[illegible]	1[illegible]65303.[illegible]	[illegible]
8.15	731.5[illegible]	465[illegible].[illegible]58[illegible]	3227340.3	[illegible].701133
10.00	564.3[illegible]	5640[illegible].[illegible]	564[illegible]	1[illegible].94[illegible]24
12.75	294.3[illegible]	4784[illegible].1428	7777338.3	1[illegible].77[illegible]
14.60	195.[illegible]	4156[illegible].1996	[illegible]6[illegible]251.1	[illegible]
17.80	79.5[illegible]	2518[illegible].7794	798[illegible]812.[illegible]	1[illegible].[illegible]4
20.00	53.25[illegible]	213[illegible].[illegible]	[illegible]52[illegible]	9.[illegible]462
22.50	33.4562	16937.191[illegible]	3574453.[illegible]	9.737267
25.35	19.1717	1232[illegible].1939	7917231.7	9.[illegible]
29.90	1[illegible].82[illegible]	9673.9431	3646[illegible]1.9	9.[illegible]77[illegible]
32.75	7.2546	7781.0546	8343667.4	[illegible].[illegible]9447
34.50	5.573[illegible]	6633.2197	7895189.7	8.[illegible]846
40.00	1.6386	2671.6816	419[illegible]69[illegible].5	7.[illegible]1573

FINAL RESULTS OF THE EXPERIMENT(CORRECTED FOR HIGH ENERGY ACTIVITY OF THE FOIL
LEAST SQUARE CONSTANT A= .5689.755 06
LEAST SQUARE CONSTANT B=-0.1326656

MEASURED AGE WITHOUT ANY CORRECTION= 51.751349

CORRECTION FOR FINITE SIZE OF SOURCE= 2.052614
CORRECTION FOR FINITE FOIL SIZE= [illegible].093689
CORRECTION FOR DENSITY CHANGE=-0.168813
TOTAL CORRECTION FOR AGE= 1.977561

AGE OF PU-BE NEUTRONS TO INDIUM RESONANCE= 53.7289[illegible]

ERROR ANALYSIS IN AGE VALUE

ERROR IN AGE VALUE DUE TO COUNTING ERRORS=+- 3.746191
ERROR IN AGE VALUE DUE TO POSITION ERRORS=+- .2[illegible]214
TOTAL ERROR IN THE MEASURED AGE=+- 4.[illegible]444 5